

**PUBLIC UNIVERSITY OF NAVARRE**

Department of Statistics and Operations Research

Institute of Smart Cities



**Decision Making with Horizontal Cooperation and  
Environmental Criteria for Transportation:  
Optimization and Simulation Models for the Vehicle  
Routing Problem and the Facility Location Problem**

Author:

Adrian Serrano-Hernandez

Advisor:

Javier Faulin Fajardo

Pamplona, March 2018



Adrian Serrano-Hernández

Department of Statistics and Operations Research

Institute of Smart Cities

Public University of Navarre

Campus Arrosadia, s/n, 31006, Pamplona, Spain

E-mail: [adrian.serrano@unavarra.es](mailto:adrian.serrano@unavarra.es)



## *ACKNOWLEDGEMENTS*

First of all I must thank my girlfriend, Sara, who left everything in Extremadura to go along with me in our new adventure in Pamplona. Without her endless support, patience, company, and love this thesis would not have been possible. I must also thank my parents, Joaquina and Adrián, for always being with me and support me in all my difficult decisions. And my sister, Rocío, for listening to me in difficult times.

I would also express my gratitude to my adviser, Javier Faulin, for his unevaluable commitment, support, and guidance. Thank you so much.

I cannot forget my colleagues at the Department of Statistics and Operations Research, and the DECYL research group from the Public University of Navarre. And all of them that have shared a room (and inquietudes) with me: Aritz, Arkaitz, Unai, Marta, Lorena, and Pablo.

I would also like to thank Angel and Patrick for their hospitality in Barcelona and Vienna during my research stays. This is extended to all of them that helped me in Barcelona: Carlos, Aljosha, Adela... and Vienna: Christian, Markus, Maria.... Without them, the experience would not have been so good.

Finally, I have to thank Rafa, Aarón, Adri, Servan, and Jota for making my (few) visits to Almendralejo exciting stays.



## *FUNDING*

The development of my PhD studies has been conducted within the framework of the following projects:

1. TRA2015-71883-REDT. Transport, Logistics, and Smart Production. Spanish Ministry of Economics and Competitiveness.
2. CAN2015-70473. COOP-Sustainable Transportation-2: Smart Logistics and Sustainable Road Freight Transportation. *Caja Navarra* Foundation.
3. CYTED2014-P514RT0013. Ibero-American Network for Smart Logistics and Sustainable Transportation in Urban Environments. Ibero-American Program for Science and Technology for Development.
4. TRA2013-48180-C3-1-P. Horizontal Cooperation and Environmental Costs in the Management of Sustainable Road Freight Transportation. Spanish Ministry of Economics and Competitiveness.
5. IIM14196.RI1. Biorefinery in Navarre. Government of Navarre.

Likewise, these PhD studies have received financial support from the Spanish Ministry of Education (predoctoral grant FPU14/00024).

Finally, mobility activities regarding attendance to conferences and stays have received the following financial support:

1. Conferences: DECYL Research Group and EDONA, belonging to the Public University of Navarre.
2. Research stays: Spanish Ministry of Education (grant EST16/00409), Erasmus+ (SmartTransLog@EU Erasmus+ Consortium- Grant 2016-1-ES01-KA108-023465), and EDONA.





## *ABSTRACT*

### **Decision Making with Horizontal Cooperation and Environmental Criteria for Transportation: Optimization and Simulation Models for the Vehicle Routing Problem and the Facility Location Problem**

Adrian Serrano-Hernandez, Author.

Javier Faulin Fajardo, Advisor.

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Transportation is a major contributor to the development of the world economy and, at the same time, a major contributor to air pollution and global warming. Additionally, the unstoppable increase of competition as consequence of the globalization, as well as the increasingly service quality demanded by customers related to shorter times and lower costs, are forcing logistics companies to consider new managerial strategies.

In this sense, horizontal cooperation among logistic companies is seen as a real alternative for gaining efficiency and sustainability. These agreements can be summarized as any arrangement between partners, tacit or not, which involves more than one company without vertical relationship between them, i.e., no supplier-customer relationship, based on trust and mutual commitment to identify and exploit win-win situations with the goal of sharing benefits (or risks) that would be higher (or lower) than each company would obtain if they acted completely independently. Therefore, in the first part of this thesis, several simulation models have been developed to track the evolution of a coalition in order to quantify horizontal cooperation impact in both economic and environmental sides considering the existence of trust-related issues. Additionally, as a great source of cooperation, a real application consisted on the location of a biorefinery is presented, developed, and discussed.

On the other hand, environmental impacts of transportation should be measured and assessed for their integration in the existing optimization models. Thus, the second part of this thesis is devoted to the pricing through a contingent valuation survey of environmental impacts (externalities) and their internalization in the well-known Vehicle Routing Problem. In this sense, several optimization models are developed to assess the impact of the internalization of externalities on the routing decisions of logistics operations.

**Keywords:** Horizontal Cooperation, Simulation, Optimization, Vehicle Routing Problem, Facility Location Problem, Biorefinery, Pricing, Contingent Valuation Survey, Internalization, Externalities, Trust



# List of Acronyms

<b>ABS</b>	Agent Based Simulation
<b>ACA</b>	Ant Colony Algorithm
<b>CVRP</b>	Capacitated Vehicle Routing Problem
<b>CVS</b>	Contingent Valuation Survey
<b>FLP</b>	Facility Location Problem
<b>GA</b>	Genetic Algorithm
<b>GAMS</b>	General Algebraic Modeling System.
<b>GHG</b>	Greenhouse Gas
<b>GRASP</b>	Greedy Randomized Adaptive Search Procedure
<b>GVRP</b>	Green Vehicle Routing Problem.
<b>HC</b>	Horizontal Cooperation
<b>HFVRP</b>	Heterogeneous Fleet Vehicle Routing Problem
<b>L&amp;T</b>	Logistics and Transportation
<b>MDVRP</b>	Vehicle Routing Problem with Multiple Depots
<b>SA</b>	Simulated Annealing
<b>SCM</b>	Supply Chain Management
<b>SME</b>	Small and Medium Enterprises
<b>SVRP</b>	Stochastic Vehicle Routing Problem
<b>TS</b>	Tabu Search
<b>VRP</b>	Vehicle Routing Problem
<b>VRPB</b>	Vehicle Routing Problem with Backhauls
<b>VRPPD</b>	Vehicle Routing Problem with Pickup and Delivery
<b>VRPSD</b>	Vehicle Routing Problem with Split Delivery
<b>VRPTW</b>	Vehicle Routing Problem with Time Windows



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# PART I

## **INTRODUCTION**

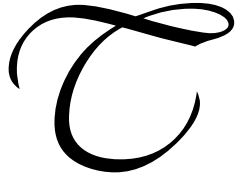






# CHAPTER 1

## INTRODUCTION



*his chapter presents a journey across the thesis.*

*It is first presented the main concepts surrounding logistics and transportation and their roles in the economic development. Special attention is paid to major logistics decisions such as the **Vehicle Routing Problem** and the **Facility Location Problem**. Both Problems play a key role in the development of this thesis regarding horizontal cooperation and environmental impacts of transportation.*

*On the one hand, **horizontal cooperation** in transportation may be applied in two directions: firstly, cooperation in deliveries through the Vehicle Routing Problem, and, secondly, cooperation in opening consolidation centers through the Facility Location Problem. Therefore, part of this thesis is dedicated to a real application of the Facility Location Problem: a huge regional project consisted on locating a biorefinery plant in Northern Spain. Through the study of that project several contributions were made on the field of the Facility Location Problem. Thus, it is convenient to describe that experience in this thesis due to its practical approach in horizontal cooperation using Operations Research techniques and its closeness to the logistics and transportation arena.*

*On the other hand, **environmental impacts** of transportation are also studied in the frameworks of the Vehicle Routing Problem and the Facility Location Problem. Here, the focus is placed on their economic valuation and internalization.*

## 1. Dissertation outline

This thesis contains five parts, eleven chapters, and three appendixes.

The first part (**Part I**) consists of one chapter (**Chapter 1**) devoted to introductory topics related to logistics and transportation.

The second part (**Part II**) reviews the related literature of this thesis through two chapters. On the one hand, **Chapter 2** describes relevant literature about environmental impacts of transportation. Special attention is paid to the emissions and pricing models as well as the *Green Vehicle Routing Problem* description. On the other hand, **Chapter 3** provides a deep literature review on horizontal cooperation, highlighting its benefits and environmental challenges.

The third part (**Part III**) deals with horizontal cooperation and contains four chapters. The first two chapters deal specifically with horizontal cooperation whereas the other two present an application of the Facility Location Problem as a strategy of horizontal cooperation. Thus, **Chapter 4** focuses on the impact of horizontal cooperation to improve service quality in the transportation arena, whereas **Chapter 5** evaluates it from the economic and environmental point of view. The methodology applied in both chapters is agent-based simulation. Additionally, a real application of the Facility Location Problem is described in the forthcoming chapters. Hence, **Chapter 6** describes the biorefinery location problem from an economic point of view and **Chapter 7** applies environmental criteria in a simplified problem. Methodology applied in the previous two chapters consists on mixed integer linear programming.

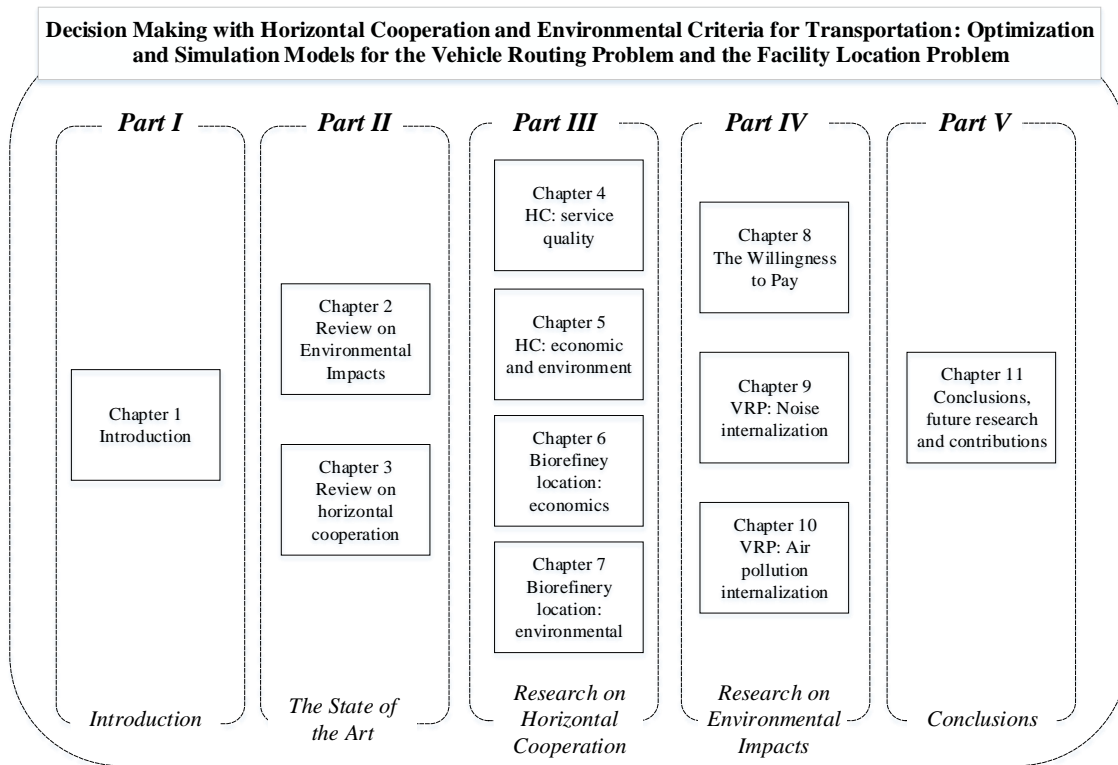
The fourth part (**Part IV**) is devoted to environmental impact on transportation. Firstly, **Chapter 8** proposes surveys for estimating the determinants for the willingness to pay to mitigate air and noise pollution from transportation. Secondly, **Chapter 9** considers the effect on routing activities of internalizing noise pollution. Externality valuation was completed using results of the previous surveys and the resulting problem was solved through a heuristic algorithm. Finally, **Chapter 10** internalizes air pollution and evaluates its impact on routing decisions using fiscal policies. In this case, externalities were assessed using European reports data and the problem was also solved with a heuristic algorithm.

The fifth part (**Part V**) contains the last chapter (**Chapter 11**) with the final conclusions, the future research lines, and the original contributions derived from this thesis.

Finally, at the end of this document, there are the bibliography and three appendixes: **Appendix 1** and **Appendix 2** show the GAMS® code for the biorefinery location problem described in the **Chapter 6**, and the **Appendix 3** shows the cover page of at the publications depicted in **Chapter 11**.

The summary of this outline is described in the Figure 1.1.

Figure 1.1. Summary of the present thesis

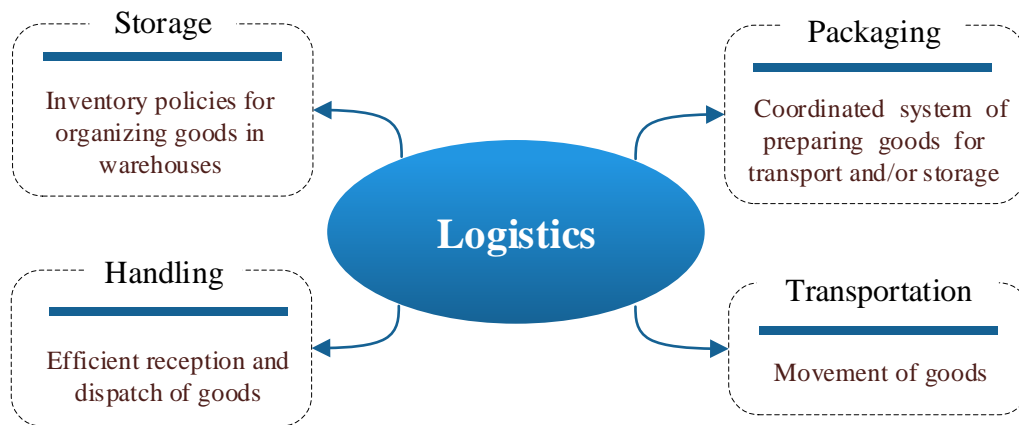


## 2. Logistics and Transportation: Concepts, Importance and Evolution

### 2.1. Introduction

The logistics concept is quite old. It has its origins in military activity that developed this tool in order to supply the troops with the necessary resources and equipment to face the long days in a war situation. It transcended to the business world in 1950s where it found its greatest field of development. From just over a decade ago to this day, the business logistics function has gained strength because markets have become more demanding as globalization has made firms to compete with companies from all around the world. In addition, the appearance of new information technologies has resulted in shorter times and lower transaction costs which forced companies to take logistic management more seriously. Therefore, logistics is one of the most used concepts within the new currents of business administration and it deals with the integration of storage, transportation, handling, and packaging of goods as shows in the Figure 1.2. It should be noted that this definition includes internal and external movements, export and import operations, and the return of materials.

Figure 1.2. Elements of the logistic activity

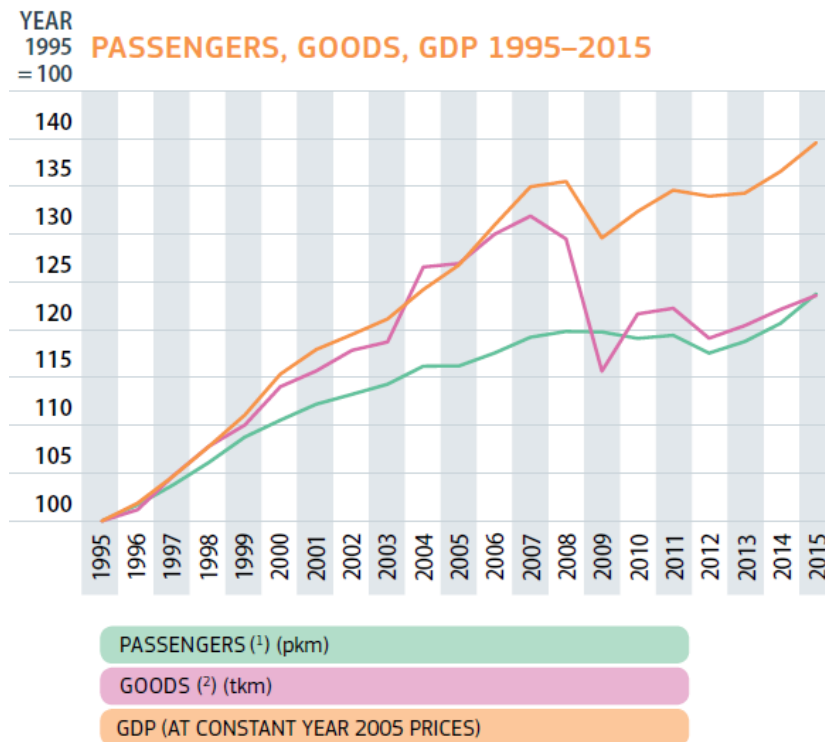


From those activities, transportation represents the most important element in logistics costs for most companies, so having a good transportation strategy is essential for their performance.

In recent years, transportation has become increasingly important in industrialized countries, where it has become a basic activity for the economic and social development, as can be seen in the Figure 1.3. Transportation main function is to connect consumers and producers, enhancing the productive specialization and the access of consumers to a growing variety of products at a higher quality. The importance of transport goes beyond purely economic aspect. The importance that leisure and the activities associated to it have in the modern societies make transport an essential activity for the personal development. In this way, transport becomes a key factor in the development of human activities, which will depend largely on the existence of transportation infrastructure appropriate to the needs of today's societies.

Nowadays, transportation is considered as an abstract concept which it is linked to many aspects in our life. That is, one is using transportation if takes a bus for going to work, or if takes the private car for going on vacation. Transportation is also used for bringing products to the supermarket and for receiving a letter from a far friend. Both the vehicles and the necessary infrastructures for this activity are part of the daily landscape of the cities and the fact of traveling to many parts of the world is not a matter of luxury anymore. Some decades ago, transportation necessities were not as great as they are today as the design of infrastructures mainly depended on the morphology of the terrain and its orography. Nevertheless, in recent years, the production model has led to a huge change in a very short time.

Figure 1.3. Evolution of EU-28 GDP, goods and passengers



Source: directly extracted from [European Commission \(2017\)](#)

The two biggest branches of transportation consists of transportation of passenger and transportation of freight. Even though those two transportation models are relevant for the economic and social growth of societies, it is the latter one the key determinant.

The importance of freight transportation has in the world economy is mainly explained by 5 factors:

- Firstly, the development of the information and communication technologies has allowed a fast and safe way of sharing information. That is, customers may search for items that are sold outside their national borders.
- Secondly, the continuously innovation in transportation means as well as the improvement of infrastructures make transporting products increasingly cheaper. Faster ships, longer trains, and better highways reduce the costs of transportation and the transported products gain competitiveness.
- Thirdly, the globalization phenomenon has a huge impact on international trade and preferences. The process of homogenization of preferences allows companies to produce at large scale in one point in the world. Later, the production can be easily transported around the world thanks to the international trade common regulations.

- Fourthly, the consumption economy is evolving to an increasingly faster products life-cycle. Rapid planned and unplanned obsolescence make any product to have a short live leading to a continuously rebooting cycle of producing and transporting new goods.
- Fifthly, the access to higher standards of life is spreading around the world, which it is heavily linked to a higher consumption and transportation. Passenger transportation is also remarkable for the economic and social development of the societies. On the one hand, the progressive improvement in private and public transportation services are offering to the citizens a reliable and cheaper way to travel. On the other hand, the increase of households' disposable income linked to the economic development are a key factor for the boom of pleasure trips.

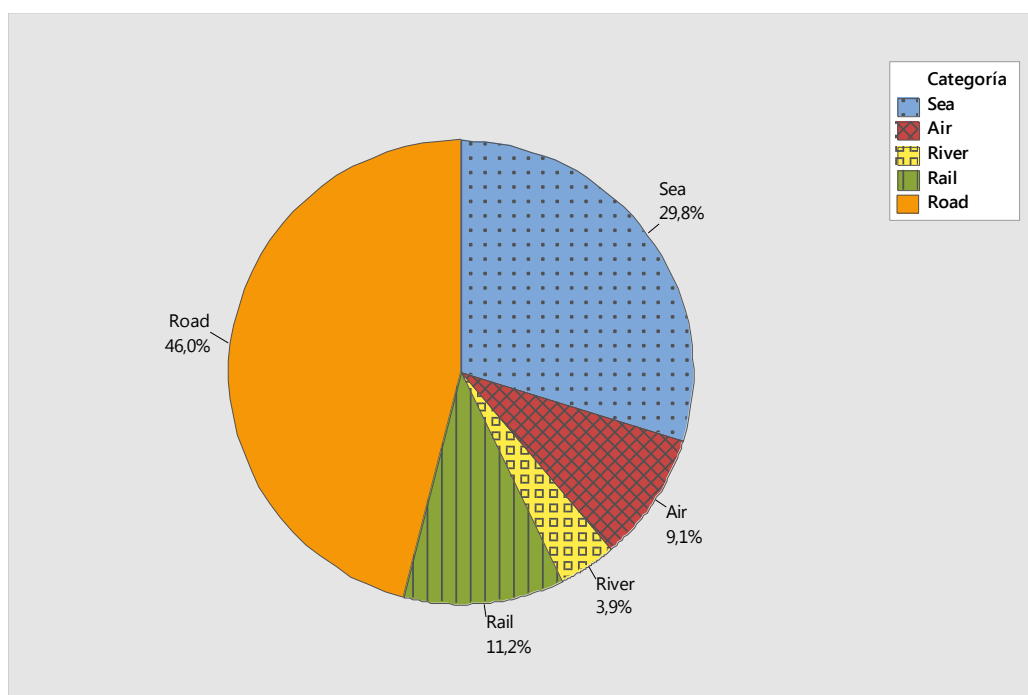
As consumer economy is spreading all around the world, consumers demand goods that may be produced in any part of the globe. Transportation networks allow transferring those goods from its origin to the final consumption point, maintaining competitive prices. The movement can be made in any transportation mode or through a combination of them (multimodality). That is the case of goods that are manufactured in China, travel by boat to a European harbor, go by train to a distribution center, and finally travel by road in a truck to a retail store. Therefore, it can be distinguished between several modes of transportation, each with particular advantages that makes it more convenient in particular situations. Table 1.1 lists those transportation modes with their advantages and disadvantages concerning freight transportation. Apart from the transportation modes showed in the table, there also exist river, pipeline, and air transportation but their share in total transportation is very low, as can be seen in the Figure 1.4. Still river transportation has also a great impact in inland areas that may find in rivers a chance for international maritime trade. Moreover, pipeline transportation is extremely convenient for transporting nonsolid material such as oil or gas at a very cheap manner. Finally, air transportation is suitable for transporting at an extremely fast speed.

Table 1.1. Advantages and disadvantages of main transportation modes

Mode	Advantages	Disadvantages
Rail	Convenient for long distances Faster than road Suitable for carrying heavy goods	Expensive for short distances Limited network Limited time schedule
Road	Relatively cheaper Fast in short distance Flexible in times and locations	Expensive for long distances Expensive for heavy goods
Sea	Cheap for heavy/bulky goods Cheap for maintaining routes Convenient for very long distances	Slow transportation Large investment on ships



Figure 1.4. Tonne kilometer freight transportation modal split for EU-28 in 2015

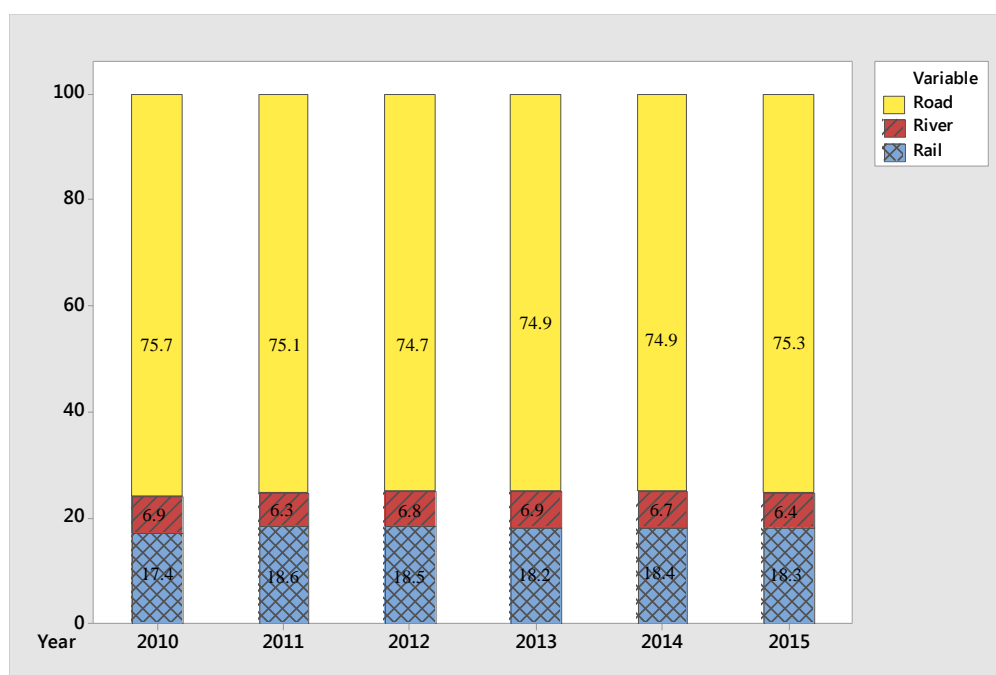


Source: Eurostat

## 2.2. Road freight transportation

Road freight transportation sector is the predominant mean as it accounts for just over three-quarters of the total inland freight transport. As can be seen in the Figure 1.5, rail and river are still very far from the utilization of the road.

Figure 1.5. Tonne kilometer inland freight transportation modal split for EU-28

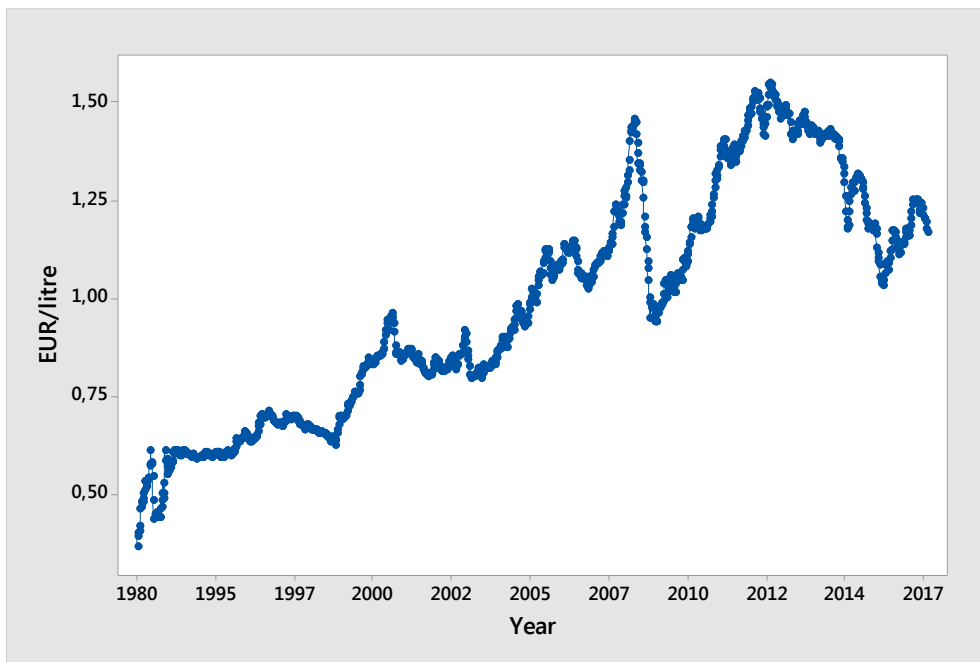


Source: Eurostat

Road freight transportation is so sensitive to external factors such as globalization, the high fuel-based dependency and the network availabilities. Globalization is a factor that has had a significant impact on the demand for freight transportation as manufacturing is increasingly specialized, fragmented, and distributed:

- Firstly, manufacturers integrate more and more components made by third parties, often from different parts of the world which leads to a demand for transportation services.
- Secondly, road transportation is particularly affected by fluctuations in prices of fuel. As can be seen in the Figure 1.6, diesel prices are highly volatile which add a risky component in the transportation activities.
- Thirdly, the improvement of the network allows reducing times and enables a more convenient road transportation system. To this respect, Figure 1.7 shows the evolution of infrastructure for road and rail transportation in the EU-28. As can be seen, motorways lengths are increasing while railways lengths are decreasing but there still many more kilometers of railways than motorways.

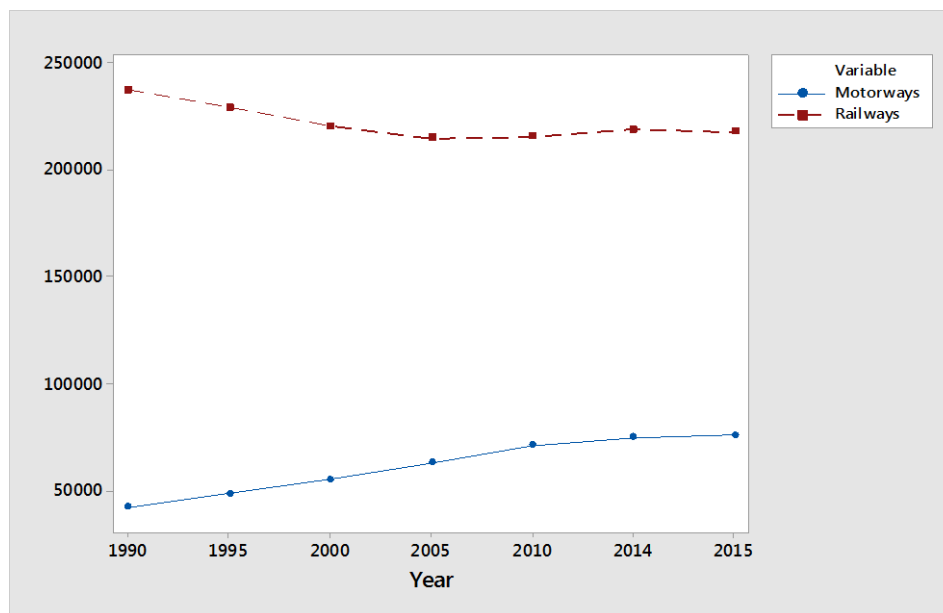
Figure 1.6. EU-28 Average EUR/litre diesel nominal price evolution



Source: Eurostat

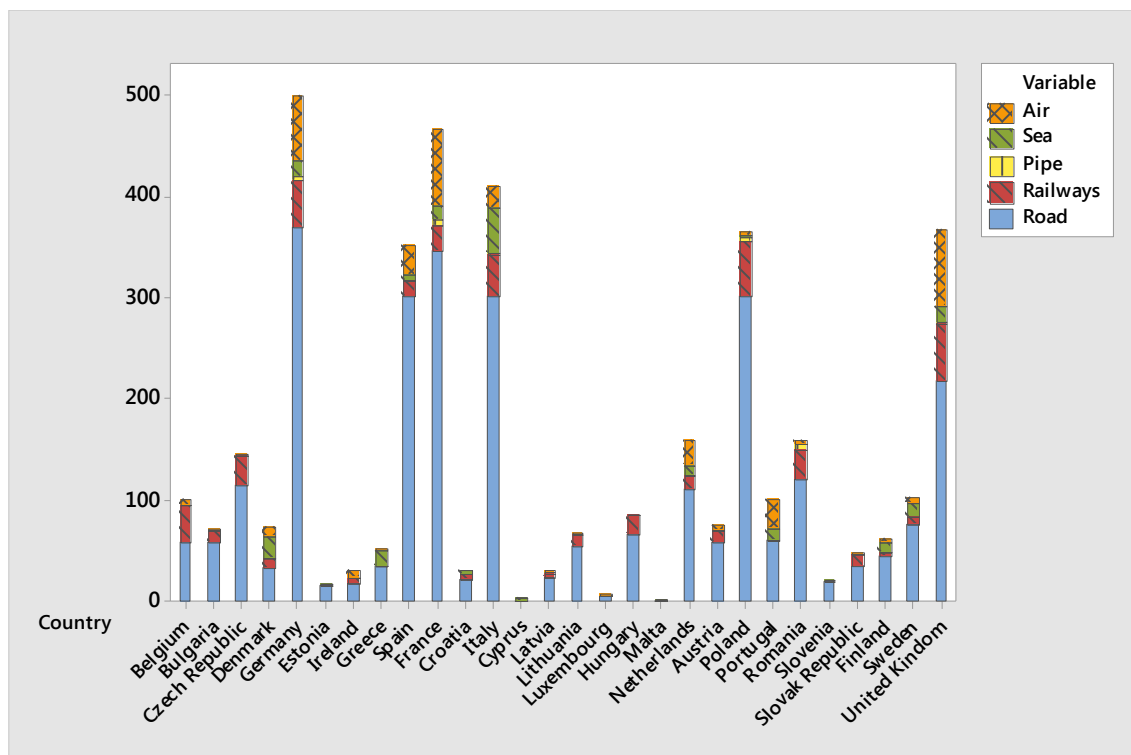
Contribution of road transportation to the economic figures in the European Union is also noteworthy. The whole transportation sector employs more than 10 million people and contributes to more than 4% to the EU-28 GDP. From those, road freight transportation accounted for most of the employment in the EU, as can be seen in the Figure 1.8.

Figure 1.7. Length (kms) of motorways and railways in EU-28



Source: Adapted from [European Commission \(2017\)](#)

Figure 1.8. Employment (thousands of people) per mode and country in the EU-28



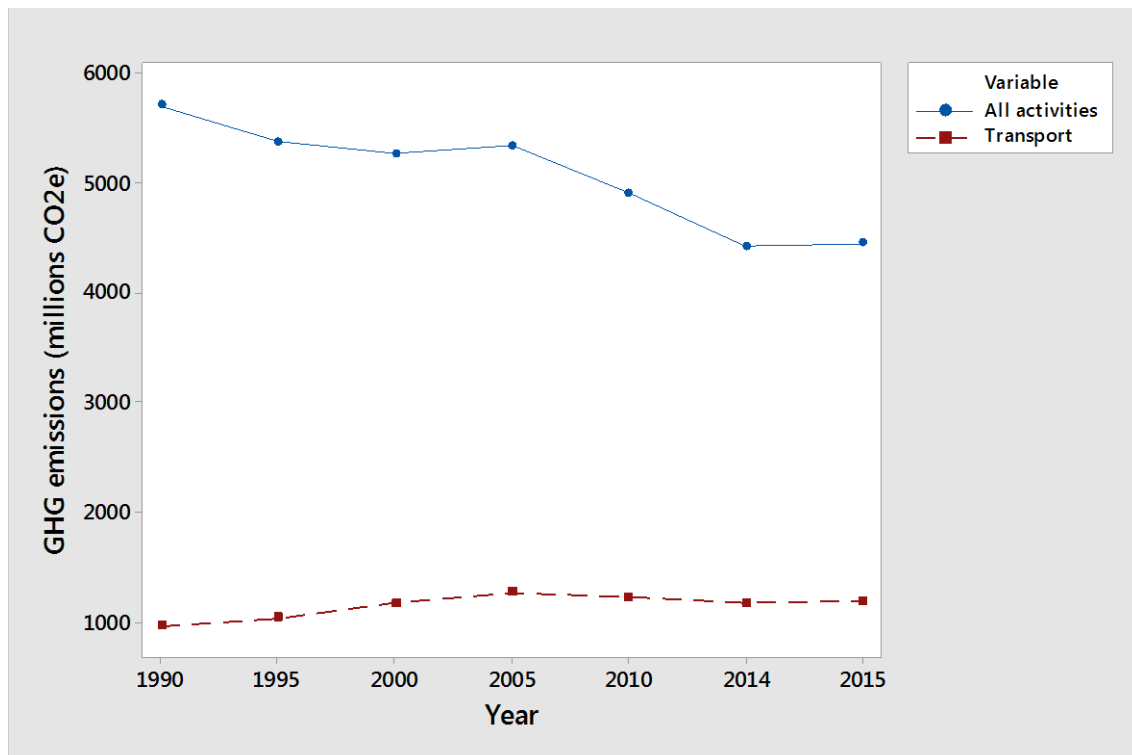
Source: Adapted from [European Commission \(2017\)](#)

### 2.3. Environmental impacts of transportation

As stated before, transportation represents an essential activity in our society. However, transportation is also responsible for a large number of social and environmental impacts such as air pollution, noise, accidents, and congestion, among others. From these impacts, it is highlight the greenhouse effect, to which the transportation activity significantly contributes. The greenhouse effect is due to the presence in the atmosphere of certain pollutants derived, mainly, from the fuel combustion. These substances prevent the evacuation to the space of part of the heat released by the planet. The main consequence of this fact is the increase in the average temperature of the Earth (what is known as global warming or greenhouse effect) and the consequent meteorological changes (climate change). The greenhouse gas (GHG) emissions consists of a list of pollutants (carbon dioxide (CO<sub>2</sub>), methane (CH<sub>4</sub>), and nitrous oxide (N<sub>2</sub>O), among others) but are usually measured as carbon dioxide equivalent (CO<sub>2</sub>e) because the CO<sub>2</sub> is the main pollutant in the GHG. Actually, as can be seen in Figure 1.9, total greenhouse gas (GHG) emissions are reducing whereas the emissions coming from the transportation activity is going up.

Given the importance of environmental effects of transportation, this thesis contains a whole chapter (Chapter 3) reviewing the literature about the topic.

Figure 1.9. GHG emissions evolution for transportation activities in the EU-28



Source: Data downloaded from European Environment Agency datasets

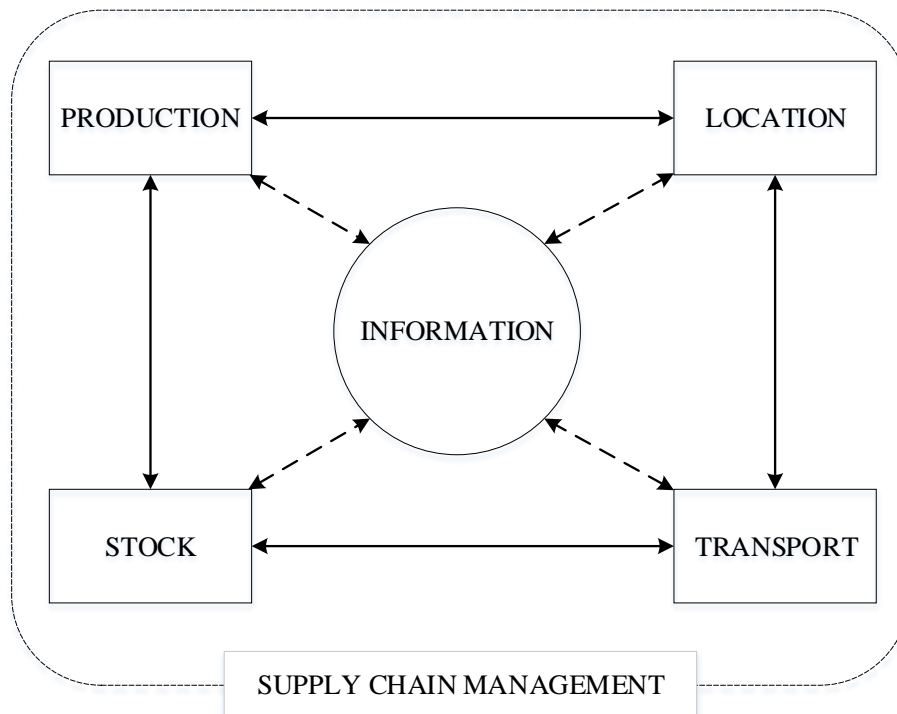
([https://www.eea.europa.eu/data-and-maps/daviz/evolution-of-ghg-emissions-in#tab-chart\\_1](https://www.eea.europa.eu/data-and-maps/daviz/evolution-of-ghg-emissions-in#tab-chart_1))

## 2.4. Supply Chain Management

Freight transportation is extremely linked to Supply Chain Management (SCM). Generally speaking, SCM can be described as the processes needed to provide the right product to the right customer at the right time at a right cost. **Chopra and Meindl (2015)** provided in-depth introduction to SCM identifying 5 core items for a successfully supply chain (Figure 1.10).

- Firstly, production consists of identifying the products a market needs and the company can provide. Therefore, new product design as well as the good characterization of products requirements are of highest interest for any company.
- Secondly, a good management of stocks helps the company to avoid risks of running out of inputs/output while reducing the excessive costs of maintaining abusive inventories.
- Thirdly, facility locations (for raw materials, warehouses, factories, and retailers) should be carefully selected in order to minimize the costs of the whole chain.
- Fourthly, as transportation links the echelons, decisions have to be made regarding the mode selection, the fleet configuration and so on.
- Fifthly, sufficient and adequate information is a requirement for the whole supply chain to work properly.

Figure 1.10. Core items in Supply Chain Management



### 3. Logistic decisions: the Vehicle Routing Problem and the Facility Location Problem.

#### 3.1. Introduction

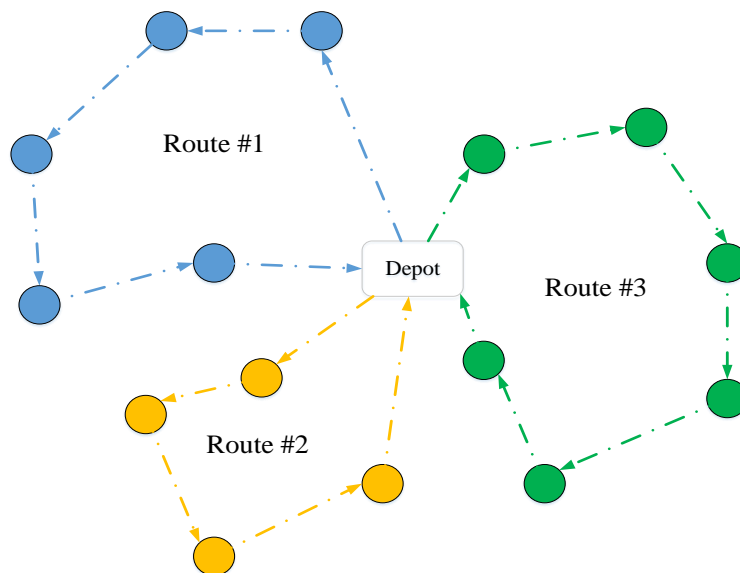
The configuration of a supply chain requires for a large range of logistics decisions. To this respect, the decisions about where to open a consolidation center (Facility Location Problem) and how to serve the customers from that consolidation point (Vehicle Routing Problem) surge as the two major logistics decision topics.

#### 3.2. The Vehicle Routing Problem

Vehicle Routing Problem (VRP) is one of the most studied problems in combinatorial optimization with plenty of real applications (Toth and Vigo, 2014). Datzig and Ramser (1959) provided the first mathematical formulation for a problem consisted in distributing fuel to petrol stations. From this moment, thousands of publications have appeared with many variants of that original problem.

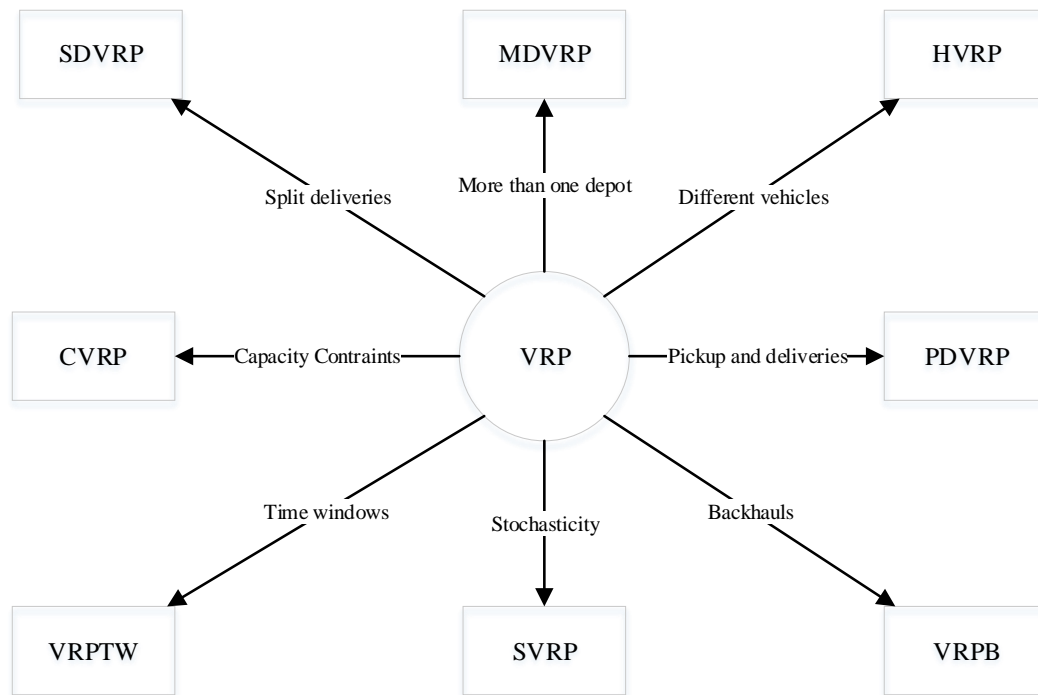
The objective of the classical VRP is to minimize the distance driven by a fleet of vehicles to serve a set of customers. Each customer has known demands that must be satisfied and the vehicles start and end their routes at a central depot. The Figure 1.11 shows an illustrative example of a VRP with 3 routes in with the circles represent the customers.

Figure 1.11. Vehicle Routing Problem example



In the existing literature, different versions of the classic VRP problem have been proposed in order to approach to real contexts. These variants are formulated by incorporating additional variables and restrictions to the original problem. In this sense, the heterogeneous fleet VRP (HFVRP), appears when vehicles differ in equipment, capacity, age, cost structure or even level of emissions, if these are considered. In the literature there are numerous variants of the HFVRP problem, depending on whether the fleet of vehicles is limited or unlimited and the type of cost considered. In general, problems with a limited number of vehicles are called ‘heterogeneous VRP’ (HVRP), while the unlimited version is called ‘Fleet Size and Mix’ (FSM). When the sum of the demands of all the customers exceeds the capacity of the vehicle, we are dealing with the Capacitated VRP (CVRP). If there exist a time restriction for visiting one or more customers, then, the VRP turns into the VRP with Time Windows (VRPTW). This VRP variant has received much attention due to its practical importance as it is quite frequent in urban distribution to face customers that are only available during a specific time interval. In the literature a distinction is made between hard and soft time windows. In the case of hard time windows, if a vehicle arrives too early, it is allowed to wait for the client until the vehicle is ready to start the service, although it is not allowed to arrive later than the latest time. In the case of soft time windows, the customers’ schedules may be violated but a penalty cost is considered in the objective function. The VRP with multiple depots (MDVRP) is a generalization of the VRP problem and is characterized by having more than one depot to serve customers. The problem has a known fleet sited at each depot and the routes assigned to each vehicle have to start and end in the same depot. For solving the MDVRP, it is also required to solve the assigned problem derived from allocate each customer to each depot. When in the VRP it is considered at the same time the pickup and delivery of goods the problem is then called VRP with Pickup and Delivery (PDVRP). Note that in the PDVRP, pickups and deliveries can be made in any order. If the specific order of first visiting the customers to deliver goods and later visiting the customers to collect goods is applied, then the problem is considered to be a VRP with Backhauls (VRPB). The VRP with split deliveries (SDVRP, Split Delivery VRP) is the variant in which it is allowed that the same customers can be served by different vehicles (or twice). It occurs when the sizes of customer orders are larger than the capacity of the vehicle. The Stochastic VRP (SVRP) surges when there exist stochasticity in one or more elements in the classical VRP. For instance, the VRP with random travel times or random customers demands. Note that all variants here described can be combined in order to cover a more specific problem, for instance the CVRPTWB refers to a capacitated VRP with time windows and backhauls. The Figure 1.12 summaries the VRP variants here described whereas a complete survey is provided in [Caceres et al. \(2015\)](#).

Figure 1.12. Main VRP Variants



### 3.2.1. The Green VRP

Irruption of new concerns related to environmental issues has forced Operations Research to take them into its analysis. As a result, applications that already worked have evolved to acquire this new perspective. Focusing on the transportation research, the traditional VRP previously described has also been touched by the green paradigm and new VRP models incorporate the environmental side. Thus, since 2006 new VRP models have to do with environmental-friendly approaches which lead to more complex combinatorial optimization problems and data requirements, following this general green model formulation:

$$\text{Minimize traditional cost} + \text{environmental cost}$$

$$s. t. \text{constraints}$$

In a VRP with environmental criteria, objective function can be either 100% environmental (just environmental cost) or a combination of both cost (traditional + environmental). Note that in the second approach, pricing environmental externalities is, therefore, essential. Otherwise, it is not possible to compare both costs. On the other hand, in 100% environmental objective, pricing is not required as it is optimized a single element (i.e. kg of CO<sub>2</sub>). However, homogenization of elements is needed to take into account several environmental externalities. Traditional costs include costs driver, energy cost, fixed costs of vehicles, maintenance costs and toll costs.



Environmental cost includes air pollution costs, climate change costs, noise costs, accident costs, etc. Finally constraints are the classical one and depend on the VRP variant.

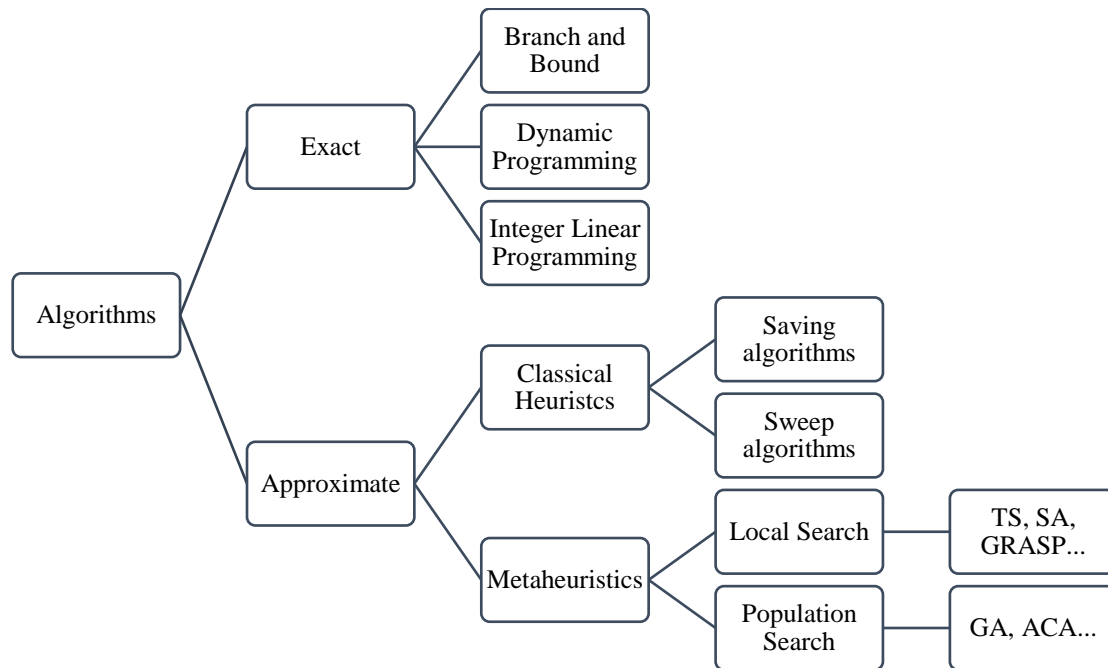
According to [Lin et al. \(2014\)](#) environmental VRP can be divided into three groups: (i) Green VRP which deals with energy or fuel consumption minimization, (ii) Polluting Routing Problem whose objective is minimize GHG emissions, and (iii) VRP in reverse logistic. In practice, differences between GVRP and PRP are difficult to see because both are based on fuel consumption estimations so the former leads to the latter. Research in this field has shown that significant CO<sub>2</sub> – fuel consumption reduction can be achieved when objective functions become greener. In this sense, [Palmer \(2007\)](#) and [Ubeda et al. \(2011\)](#) are good examples in how to integrate CO<sub>2</sub> minimization into optimization problem. Regarding VRPRL, it focuses on distributional aspects when collecting/recycling wastes or end-of-life.

Finally, this thesis presents several applications of the green Vehicle Routing Problem. [Chapter 9](#) and [Chapter 10](#) in [Part IV](#) give insights on the internalization of externalities and its effects on both environmental and economical invoices.

### *3.2.2. Solution approaches*

VRP is a NP-hard combinatorial optimization problem and exact solution can only be found in relatively small size problems. Therefore, (meta)heuristics are commonly used in practice. They are powerful solution approaches which implies an experience-based methodology to find good solutions through iterative processes in relatively short computational times. Both are equal in the sense that they do not guaranteed optimal solution but heuristics are often problem-dependent while metaheuristics are problem-independent strategies that can be applied to a large range of problems. Frequent algorithms approaches are listed in the Figure 1.13 in which a first broad classification is made as previously indicated: exact and approximate. Approximate algorithms can also be divided in the classical heuristic ones and the metaheuristic ones. Classical heuristics mainly comprises the savings algorithm developed by Clarke and Wright, (1964) and the sweep algorithm, initially proposed by Gillet and Miller (1974). Among the metaheuristics algorithms, several classifications can be made attending to the strategy developed. In the Figure 1.13, it is shown two common strategies based on local search and population search. Thus, Tabu Search (TS), Simulated Annealing (SA), and GRASP (Greedy Randomize Adaptive Search Procedure) are frequent local search algorithms, whereas Genetic Algorithm (AS), and Ant Colony Algorithm (ACA), are examples of population search algorithms. Note that a deep and formal definition of the aforementioned algorithms are out of the scope of this thesis. Nevertheless, a complete review on the most frequents algorithm can be read in [Caceres et al. et al. \(2015\)](#).

Figure 1.13. VRP solution approaches



### 3.3. The Facility Location Problem

Consequences of choosing a bad place to locate a facility may be dire. Lack of customers, difficulty of replacing stocks, rising transportation cost... will hit business profitability endangering its own survival. Appropriate location of industrial plants is particularly important to contribute to business objectives, so it should not be done superficially. Therefore, it is required to analyze all alternatives and investigate conditions surrounding them in terms of infrastructure and supply.

As described by [Daskin \(2015\)](#), qualitative analyses of location have been the predominant methodology in the past. They consist of listing factors and assessing them in a qualitative way prioritizing some factors over others. Depending on the business to set up, those factors range from the existence of natural resources (water, raw materials...) to government issues (subsidies, taxes...). Even though, the existence of closer source of raw materials has been a decisive factor location in the past when the transportation cost was very high. Today, raw materials and energy resources such as oil, electricity or natural gas, are transported over long distances in a very cheap manner ([Hummels, 2007](#)). Transport and communications is also a determinant factor. Typically, industrial plants are located in well-communicated areas in order to facilitate the arrival of raw materials, employees and customers; and the leaving of their production, as well as due to safety issues ([Martinez-Gomez et al., 2015](#)). Thus, having a good transportation is critical, particularly for industries that displace a large volume of heavy or perishable goods, for instance in the fruit or vegetable sector as explained by [Etemadnia et al. \(2015\)](#). Finally, labor related factors are also

important and highly studied in facility location decisions. Availability, qualification and cost of labor may determine potential location of plants, especially in multinational companies (Dustmann and Glitz, 2015). When abundant unskilled labor is needed, often large companies from developed countries set up their industrial processes in underdeveloped areas, where wages are lower and there is no trade union tradition (offshoring, Ellram et al., (2013)). A deeper analysis of factors affecting location decision can be found in Chan (2001).

Quantitative analysis aims to assign objective values to each alternative place to select the most appropriate one. It is based on developing mathematical models that can solve the problem of location, usually focused on answering the following questions: how many facilities should we place? where should we place them?, how big should they be?... The answers to these questions depend on the problem context. In some cases, such as the problem of locating retail stores, generally they should be placed close to customer flows. In the location of a landfill, as remarked by Gbanie et al. (2013), we will want to place them as far as possible from large population centers. A combination of qualitative and quantitative analysis is usually a good option. The big disadvantage of qualitative analysis is that a location decision is made based on a subjective evaluation. Although quantitative analysis overcomes this disadvantage, it does not permit incorporating unquantifiable factors that have a significant impact on the location decision. For example, quantitative techniques can consider the operating and transportation costs, but intangible factors such as the potential for labor disputes, or supplies reliability are difficult to capture, although important in decision-making.

Finally, Facility Location Problems is also extremely related to the horizontal cooperation paradigm as it is common to share/open consolidation center among logistics companies. Therefore, the study of this kind of problems is of highest interest for the development of this thesis. Thus, Chapter 6 and Chapter 7 in Part III describes a real application of a Facility Location Problem.

To sum up, given a set of facility locations (potential) and a set of customers to serve, the FLP consists of determining which of those facilities should open and assign the customer to the facilities in order to optimize an objective function, typically related to minimum distances.

## 4. The sharing economy: an approximation to Horizontal Cooperation

### 4.1. Introduction

Companies such as *BlaBlaCar* [<https://www.blablacar.es>] or *Airbnb* [<https://www.airbnb.es/>] have achieved a strong growth during the last years exploiting the concept of the sharing economy. The business model of these companies is to contact individuals to share a good or service in exchange for small commissions and the income generated through the advertising of

their web sites. In this way, private individuals find their trips or stays more economical and the company receives a monetary compensation for its service. These companies, however, are only the tip of the iceberg of this phenomenon that is permeating all of the society (Zervas et al., 2015). In fact, the way people buy and use their products and services is continuously changing and now they are adapting to the sharing economy (Möhlmann, 2015), an economic model based on sharing, exchanging or renting a good or service instead to acquire it in property. The collaborative economy has the potential to move global and local economies towards sustainability and efficiency (Boons and Lüdeke, 2013).

#### *4.2. Horizontal Cooperation*

Cooperation between companies is not a new phenomenon and has been widely studied in business literature (Schmoltzi and Wallenburg, 2012). In other areas, business collaboration has allowed many kinds of agreements between companies, which are the basis of numerous business terms such as joint ventures, strategic alliances, consortiums, franchises, buying groups, etc. To this respect, supply chain management can be seen as a kind of cooperation mechanism, however cooperation has vertical structure (suppliers, producers and customers). Literature focusing on horizontal relationships are much more difficult to identify (Lietner et al., 2011).

Although the European Union (2001) officially defines horizontal cooperation as those coordinated practices between companies that operate at the same level of the market, other authors have tried to provide nuances to this definition that is continuously evolving. Thus, Cruijsen et al. (2005) claimed that horizontal cooperation is an interesting approach to reduce costs, improve the quality of service or protect a position in the market. Bahinipati et al (2009), meanwhile, defines it as a business agreement between several companies that belong to the same level of the supply chain in order to achieve common objectives. Due to horizontal cooperation can occur between competing companies, it is especially advantageous when applied to secondary activities in which companies can mutually benefit while maintaining competition in the main activity (Guajardo and Rönqvist, 2014).

#### *4.3. Collaborative urban distribution*

Companies in their logistics activities have to face important challenges. Thus, they have to design complex distribution and business strategies that allow them to combine competitiveness and economic efficiency. These issues are fundamental, especially for small and medium-sized enterprises (SMEs), which usually do not have the economic, human and technical resources necessary to solve the complex mathematical models related to logistics optimization. A possible strategy that SMEs can follow to improve their competitiveness, while reducing their environmental footprint, is to take advantage of economies of scale through collaboration with

other companies. It should be noted that, in the road freight transportation, 24% of the vehicles in the European Union travel empty (deadheadings). At the same time, there is growing global concern about climate change and environmental risks related to CO<sub>2</sub> and other harmful gases emissions. It is well known that transportation activities are among the main contributors to this phenomenon. Additionally, the growing increase in competition mainly due to globalization, as well as the increasing expectations from customers, have narrowed the profit margins of the logistics companies.

The current urban distribution is still immersed in obsolete models. Urban distribution is mainly based on diesel-fuel vehicles that cause a great environmental impact (CO<sub>2</sub> emissions and noise, among others) and collapse the city centers. Likewise, the boom of e-commerce in recent years is fairly aggravating the situation in the center of large cities (Koc et al, 2015). Complete solutions do not exist but there have been steps in the right direction. Firstly, the increasingly utilization of electric vehicles could solve the environmental issues of urban distribution (Juan et al., 2016), while horizontal cooperation between the SMEs would also contribute to reducing pollution. Secondly, horizontal cooperation would provide greater efficiency in the distribution by decreasing the number of vehicles needed to carry out the distribution, which would lead to a reduction of vehicles. As a result, sector profitability would be favored by benefiting from economies of scale and generating a large amount of valuable information for subsequent strategic decision-making (for example, opening consolidation centers). That is why this new paradigm should serve as a catalyzer of for horizontal cooperation and use the culture created in relation to the sharing economy to take advantage of all the opportunities that the current environment offers.

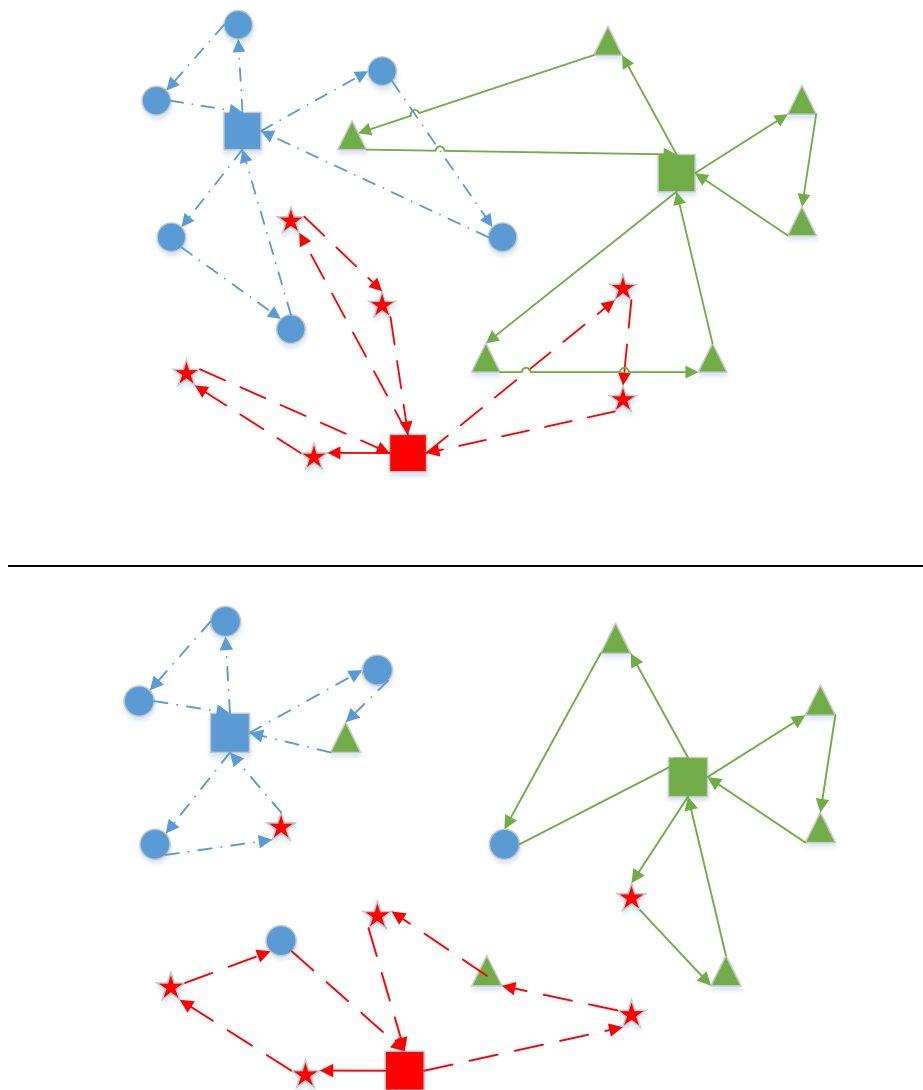
Given the above, it is not surprising that logistics cooperation is starting to be considered as a real option to increase the efficiency of their activities. This would allow to increase the margin of optimization of its operations to be enhanced by the economies of scale. By reducing operating costs, a better price can be offered to reinforce the position in the market while reducing environmental impact, resulting in more efficient logistics operations due to savings in empty trips and increasing load factors (Danloup et al., 2015).

The Figure 1.14 shows an illustrative example of Horizontal Cooperation in the classical vehicle routing problem. The network on the top corresponds to a scenario in which companies do not collaborate with each other. In this case, each of the three companies has a warehouse from which to deliver goods to their customers. It is assumed that companies optimize the routes in order to minimize the distance traveled, subject to customer demands are satisfied, vehicle is not overloaded, and starts and ends at the warehouse. On the other hand, the network on the bottom shows the same problem but in a collaborative scenario. The three companies have to satisfy all customer and they are allocated in a more appropriate way. In the collaborative scenario, the routing design from a much broader perspective allows to significant savings in distances with respect to its non-cooperative counterpart. The main consequence is a saving in the costs

associated to transportation (by reducing distances and/or number of routes) while reducing the environmental impact resulting from a reduced use of the fleet. In addition, it is important to emphasize that reducing distances also may lead to a reduction in times so the quality of service, measured in delivery times, is also positively affected.

However, multiple factors must be taken into account for the relationship to be fruitful. For example, the correct choice of the partner with whom to collaborate (Adenso-Diaz et al., 2014), the different characteristics and roles that can be played by the members of the cooperation, and the policy of distribution of the costs and benefits that are generated as a result of the collaboration (Guajardo and Rönnqvist, 2016) are the most remarkable sources of conflicts related to the application of collaborative policies.

Figure 1.14. VRP without (top) and with collaborative practices (bottom)





**PART II**

**THE STATE OF THE ART**





## CHAPTER 2.

# ENVIRONMENTAL IMPACTS OF TRANSPORT: FROM THE EXTERNALITIES TO GREEN LOGISTICS

*A review on environmental impacts on transportation is presented in this chapter. After a brief introduction, a complete description of freight transportation externalities is described in detail, highlighting air pollution. Afterwards, several emissions models are explained. The chapter concludes with the topic of internalization in which some pricing models are also listed.*

*Finally, many gaps are drawn from the literature encouraging further research on pricing techniques.*

## 1. Introduction

Green Logistics extends the traditional definition of logistic by explicitly taking into account other non-traditional external factors within all aspects of logistics: transportation, storage, inventories management, materials handling, and information processing. Therefore, green supply chain cares about environmental issues such as emissions of greenhouse and another pollutant gases, noise, and the use of scarce resources, among others, which are popularly known as externalities (Dekker et al., 2012). Consequently, a definition of each single ‘green’ echelon should be provided.

- Firstly, transportation is both the most visible echelon and the most polluting activity. In 2015, it caused about 25% of total greenhouse gas emissions and around a third of CO<sub>2</sub> total emissions in the European Union (European Environment Agency, 2016). Thus, major effort must be made regarding the green transportation.
- Secondly, concerning products and inventories, the green point is that some products are friendlier to the environment than others. Concepts such as carbon footprint when producing and reverse logistic when collecting waste must be taken into consideration in order to define a green inventories management.
- Finally we need to deal with green facilities which involve internal transport, energy use, and traffic jams around their buildings (Geerlings and van Duin, 2011). Additionally, the way facilities manage the whole system energy (energy savings installation, solar cells, heating/refrigerating systems...) would characterize a green facility.

Each echelon in a supply chain has an environmental impact. Decisions such as where products came from, how production/distribution concepts are defined, including the type, number and location of facilities, and the choice of transportation means, are potentially optimizable variables with the purpose of getting a green logistics system (green supply chain). However, road transportation is the most polluting activity as it accounts for more than 70% of GHG emissions from transportation (European Commission, 2017). For that reason, the focus is on road transportation as the key polluting agent in the supply chain.

## 2. Road freight transportation externalities

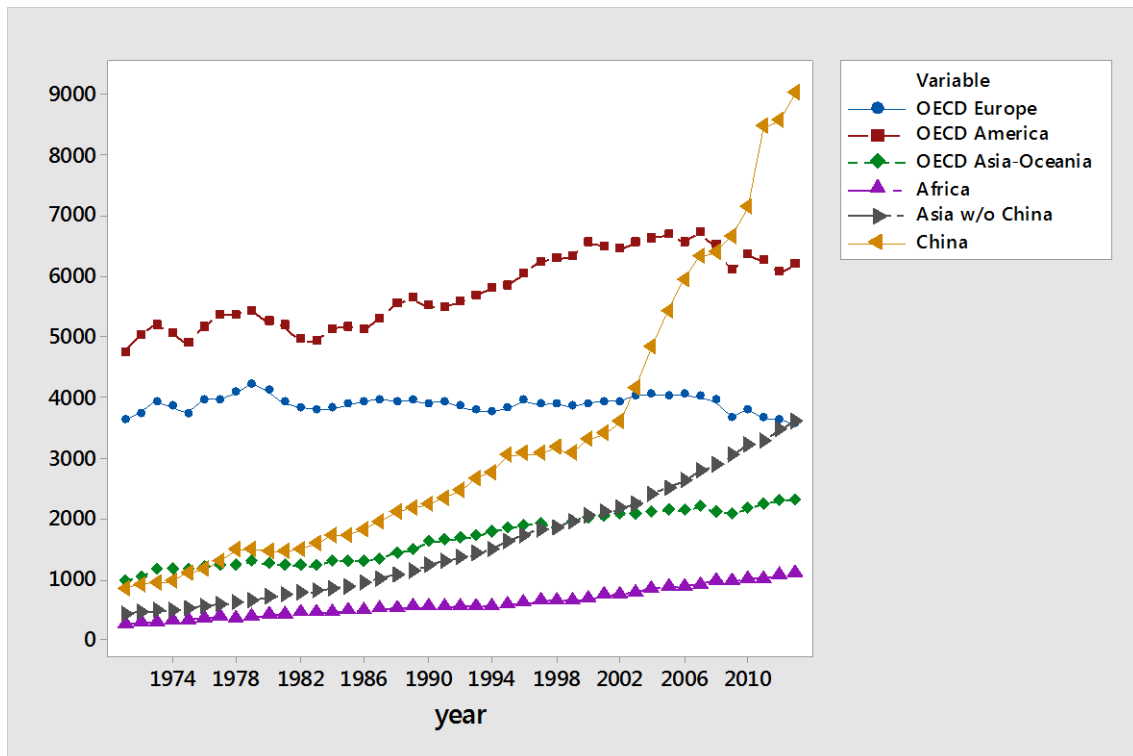
Air pollution is one of the main externalities derived from road freight transportation (Demir et al. 2015). Air pollution is caused by emission of air pollutants such as particulate matter (PM), NO<sub>x</sub> and non-methane volatile organic compounds that affect people, vegetation, global climate and materials. Climate change or global warming impacts of road transportation are, mainly, generated by emissions of greenhouse gases (GHG): carbon dioxide (CO<sub>2</sub>), nitrous oxide (N<sub>2</sub>O) and methane (CH<sub>4</sub>). Nevertheless, CO<sub>2</sub> is the dominant anthropogenic GHG, and the remaining

GHG can be expressed as CO<sub>2</sub> equivalent (CO<sub>2</sub>e) (Lera-López et al. 2014a). The road transportation, as the primary mode of freight movement, is the largest source of freight-related CO<sub>2</sub> emissions in developed countries. International agreements such as ‘Kyoto Protocol’ and later ‘Doha Amendment to Kyoto Protocol’ are pushing countries to accomplish the commitment regarding GHG emissions reduction and stand up for specific plans to reach common goals in 2020 for the second period (UNFCCC). National policies have a great influence to companies that start to promote internal strategies towards a greener supply chain that leads to an improvement at all levels (production, logistics and other operations). Countries such as UK have implemented strict government regulations aiming to reduce CO<sub>2</sub> emissions (Ramathan, 2014). According to International Energy Agency (2017), worldwide CO<sub>2</sub> emissions from fuel consumption raised 56.4% from 1971 to 2013 whereas in OECD countries it raised 9.4% in the same time period (see Figure 2.1). That is, the CO<sub>2</sub> emissions in transport sector and their contribution to climate change are one of the main problems in the sustainable management of logistic activities.

Laffont (2008) defined an externality as the indirect effect of consumption or production activity on the utility function of a consumer or a producer. Indirect implies that it does not concern agents involved in such an economic activity and that effect is not reflected in the price system. Externalities can be positive or negative. Employment is a positive externality of setting up a chemical industry; however, water pollution produced by its activities is a negative externality. Both externalities affect somehow utility function of consumers and producers and they are out of traditional cost-based price system. Research interest in externalities of freight transportation has continuously expanded because of the increasing impacts on economy, environment, climate, and society. For example, Ranaiefar and Amelia (2011) classified road freight transportation negative externalities into four categories: i.e. economic, social, ecologic and environmental (Figure 2.2). From all externalities, accidents, road damage, congestion and environmental damage have received most of the attention.

Regarding the accidents, the more vehicles on the road, the more likely accidents occur. Accidents externalities arise when a truck increase such probability. However, it is rational that the more vehicles on the road, the slower they drive due to congestion issues. Therefore, an extra vehicle is increasing the accidents risk but, at the same time, every accident would be less severe because of higher congestions and lower speeds. As a result, a net-accident externality is difficult to compute and it could be positive if we considered that live savings are achieved (Parry et al. 2007). On the other hand, purely objective accident cost include damages in vehicles, services cost (police and firefighters), healthcare cost and personal cost (economic output lost, pain, dead...). Methodologies to estimate those accident cost include, mainly, number of accidents and insurances fees

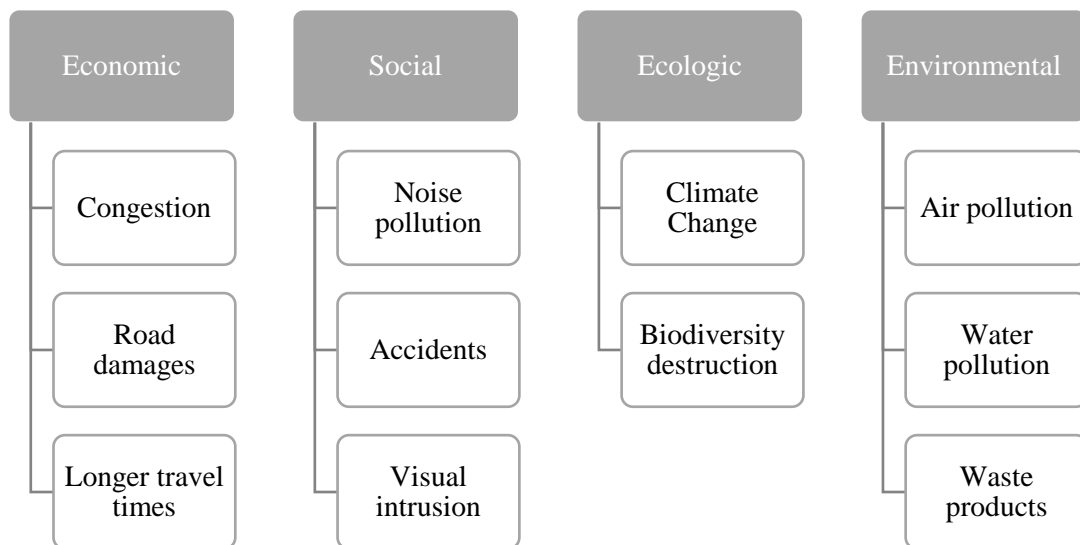
Figure 2.1. CO<sub>2</sub> emissions from fuel consumption (millions of tons)



Source: Data downloaded from European Environment Agency datasets

(<https://www.eea.europa.eu/data-and-maps/data/national-emissions-reported-to-the-unfccc-and-to-the-eu-greenhouse-gas-monitoring-mechanism-13>)

Figure 2.2. Classification of road freight transportation negative externalities



Road congestion is a condition characterized by slow speeds. The main impacts are longer and more uncertainty about travel times which result in negative economic effects because of an inefficient delivery of goods, services and resources. Congestion may also indirectly increase fuel costs, air pollution, noise pollution and stress levels. An adequate conversion from time into cost, combined with a demand curve, makes the analysis of the whole picture from an economic point of view possible.

Green Logistics finds environmental externalities as its best flagship and most of researchers have been (and are) interested in the environmental damage done by road transportation. This damage, mainly, includes air pollution but it is extremely related to other externalities such as climate change due to the emission of GHG. It is also remarkable noise pollution derive from the sound of engines and rolling. Finally, the ‘green’ adjective is related to environmental issues. Therefore, remaining externalities (accidents, road damage, congestion...) often are not considered and green transportation becomes into environmental-friendly transportation. The reason of this may be that some externalities can affect to the environmental ones, for example, in a congested road a vehicle pollutes more.

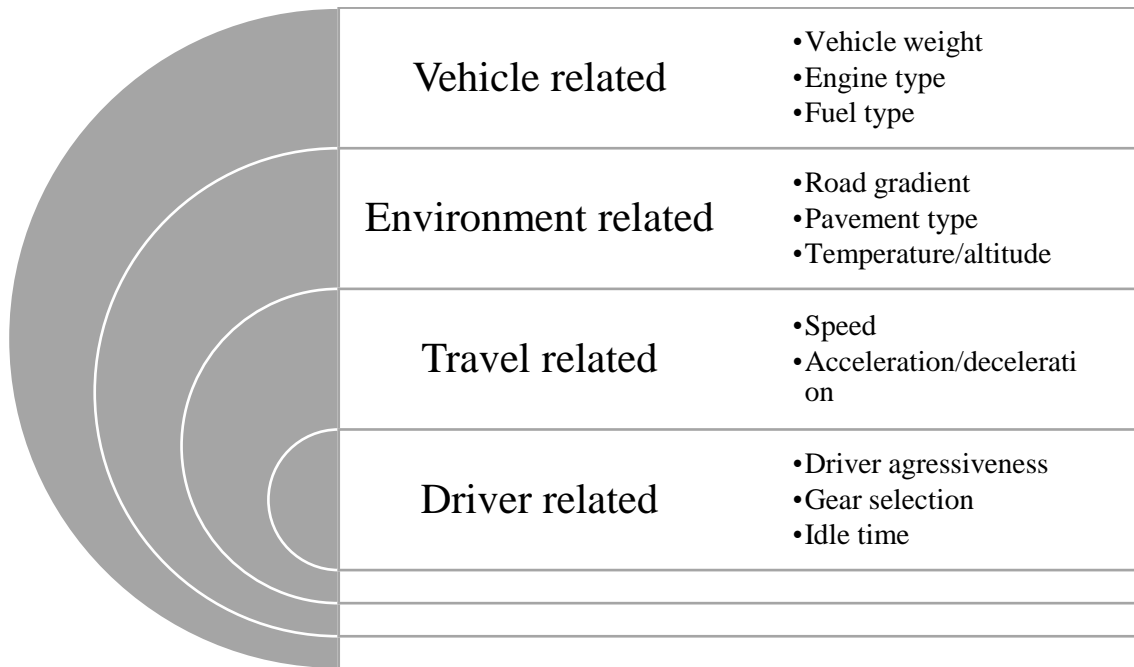
### **3. Modeling road freight transportation externalities**

The aforementioned externalities have to be modelled somehow in order to allow their inclusion into the existing optimization methods. [Demir et al. \(2011\)](#) determined that CO<sub>2</sub> emissions (predominant man-made GHG) are directly proportional to fuel consumption which implies the amount of energy spent. On the other hand, [Quartieri et al \(2009\)](#) made a review on noise models highlighting the information required.

#### *3.1. Air pollution and GHG models*

Air pollution and GHG emission models are, generally, based on energy consumption because of the direct relationship between emissions and energy consumption. [Demir et al, \(2014\)](#) made a list of factors affecting fuel consumption and, ultimately, emissions. Those factors could be divided into 4 groups: vehicle related, environment related travel related, and driver related (see Figure 2.3, based on [Demir et al. \(2014\)](#)). From those, speed and load are the most important ones and they are the reason why applying an average emission value per kilometer is inaccurate ([van Woensel, et al, 2001](#)). Then, road gradient is the next, playing an important role in fuel consumption. Here, should be taken into account down-hill does not compensate up-hill. The remaining factors still affect energy consumption marginally.

Figure 2.3. Fuel consumption factors



Rakha et al. (2003) described 2 main modelling approaches depending on the complexity level.

- Macroscopic models include average network parameters (for example, average speed) to estimate network emissions.
- Microscopic models are instantaneous energy consumption models in a high detailed level.

### 3.1.1. Macroscopic Model 1 Network for transport and environment (NTM). *NTM Road (2010)*

NTM model requires a wide range of data such as distance, load factors, and type of road (motorway, urban and rural).

The emission function (CO<sub>2</sub> Kg) is described in the Equation 2.1:

$$\epsilon(D) = \sum_{i=1}^3 f(lf)_i \cdot D_i \cdot e_{CO_2e} \quad (2.1)$$

$f(lf)_i$  is the fuel consumption (liter/kilometer) at a specified load factor  $lf$  for each type of road  $i$  (motorway, urban, rural). Being  $F$  the fuel consumption of an empty/full vehicle (litre/km) and  $lf$  the load factor can be calculated as described in Equation 2.2:

$$f(lf)_i = F(empty) + (F(full) - F(empty))lf \quad (2.2)$$

Where  $D_i$  is the total distance travelled in each type of road and  $e_{CO_2e}$  is the emission factor (normally 3.13 kg/litre diesel fuel (Coe, 2005)).

### 3.1.2. Macroscopic Model 2. Methodology for calculating transportation emissions and energy consumption (MEET) model. Hickman et al. (1999).

In this case, MEET model requires speed, road gradient, distance, and load as input to compute the emissions. Actually, the emission function ( $CO_2$  g) is described in the Equation 2.3:

$$\epsilon = F \cdot GC \cdot LC \cdot Distance \quad (2.3)$$

Where  $F$  is the rate of emissions (g/km) for an unloaded vehicle on a flat road. Being  $v$  the average speed,  $K$  and  $a - e$  predefined and known parameters which depend on weight class vehicle;  $\epsilon$  can be calculated as described in the Equation 2.4:

$$F(v) = K + av + bv^2 + cv^3 + \frac{d}{v} + \frac{e}{v^2} \quad (2.4)$$

Where  $GC$  is the road gradient correction factor. Being  $v$  the average speed and  $A_0 - A_6$  predefined and known parameters which depend on weight class vehicle;  $GC$  can be calculated as described in the Equation 2.5:

$$GC(v) = \sum_{i=0}^6 A_i v^i \quad (2.5)$$

Where  $LC$  is the load corrector. Being  $v$  the average speed, and  $k$  and  $n - u$  predefined and known parameters which depend on weight class vehicle;  $LC$  can be calculated as described in the Equation 2.6:

$$LC(v) = k + nv + pv^2 + qb^3 + \frac{r}{v} + \frac{s}{v^2} + \frac{t}{v^3} + \frac{u}{v} \quad (2.6)$$

All parameters used in MEET are extracted from real-life experiment carried out in 1999. Thus, note that technology improvements will have changed those parameters.



*3.1.3. Macroscopic Model 3: Computer programme to calculate emissions from road transportation (COPERT) model. Ntziachristos and Samaras, (2000).*

Similar data are required for the COPERT model, therefore, researchers should account for speed, traveled distance, vehicle engine, fuel, load and road gradient in order to properly estimate The emission function ( $\text{CO}_2$  g) is described in the Equation 2.7:

$$\epsilon(v, D) = (e + a^{-b \cdot v} + c^{-d \cdot v})D \quad (2.7)$$

Being  $v$  the average speed and  $a - e$  predefined and known parameters which depend on type of vehicle and fuel, payload, road gradient.

*3.1.4. Macroscopic Model 4: EcoTransIT model. Knörr et al., 2016.*

EcoTransIT model estimate energy consumption in a very accurate way requiring relatively low data (traveled distance, vehicle characteristics, and payload).

The fuel consumption function (liters of diesel) is described in the Equation 2.8:

$$FC(P, D) = \left( FC_e + \frac{(FC_f - FC_e)P}{Q} \right) D \quad (2.8)$$

Being  $FC_e$  the fuel consumption when empty,  $FC_f$  the fuel consumption when full,  $Q$  the capacity, and  $D$  the distance traveled.

*3.1.5. Microscopic Model 1. An instantaneous fuel consumption model (IFCM). Bowyer et al. (1985).*

As a microscopic model, the IFCM is data intensive and requires vehicle characteristics (mass, energy, efficiency parameters, drag force and aerodynamics values), among many other categories of data.

The fuel consumption model (mL/s) for a trip of duration  $t_0$  seconds can be computed as described in the Equation 2.9:

$$FC_t = \int_0^{t_0} f c_t dt \quad (2.9)$$

Being  $f c_t$  the instantaneous fuel consumption (g/s) as described in the Equation 2.10:

$$f c_t = \begin{cases} \alpha + \beta_1 R_t v + \left( \frac{\beta_2 M \tau^2 v}{1000} \right) & \text{for } R_t > 0 \\ \alpha & \text{for } R_t \leq 0 \end{cases} \quad (2.10)$$

Being  $R_t$  the total tractive force (kilonewtons) necessary to move the vehicle. It is calculated as a function of drag, inertia, and grade forces in the Equation 2.11, whereas Table 2.1 summarizes parameters used in the model:

$$R_t = b_1 + b_2 v^2 + \frac{M \tau}{1000} + \frac{g M \omega}{100000} \quad (2.11)$$

Table 2.1. Parameters, description and unit used in IFCM

Parameter	Description	Unit
$\alpha$	Idle fuel rate	mL/s
$\beta_1$	Energy unitary fuel consumption	mL/kJ
$\beta_2$	Energy-acceleration unitary fuel consumption	mL/(kJ·m/s <sup>2</sup> )
$b_1$	Drag force	kN
$b_2$	Aerodynamic force	kN/(m/s <sup>2</sup> )
$\omega$	Gradient	%
$\tau$	Acceleration	m/s <sup>2</sup>
$M$	Weight	kg
$v$	Speed	m/s

### 3.1.6. Microscopic Model 2: A comprehensive modal emission model (CMEM). Barth et al. (2005).

Finally, CMEM is also data-intensive a plenty of knowledge is required for its implementation. The fuel consumption funtion (g) for a trip of duration  $t_0$  seconds can be computed as described in the Equation 2.12:

$$FC_t = \int_0^{t_0} f c_t dt \quad (2.12)$$

Being  $f c_t$  the instantaneous fuel consumption (g/s) calculated as described in the Equation 2.13:

$$f c_t = \frac{\xi \left( k N V + \frac{P}{\eta} \right)}{44} \quad (2.13)$$

Where  $P$ ,  $N$  and  $\xi$  are the engine power module, the engine speed module and the fuel rate module, respectively, which depends on other more specific parameters. Finally,  $k$  is the engine friction factor and  $V$  is the engine displacement.

### 3.2. Noise Models

Quartieri et al. (2009) showed some predictive models to measure the noise as basic statistical models. Moreover, countries have adopted their regulation to measure traffic noise, see for example the England standard (Calculation of Road Traffic Noise, developed by the Department of Transport of UK (1988)).

However, Peeters and Blokland (2007) developed the most widely used model in terms of sound power level (dBA): Improved Methods for the Assessment of Noise in the Environment (IMAGINE) which uses a weighting decibel (dBA) expressing the relative loudness of sound perceived by human ear. This methodology takes into account the two noise sources which are rolling and engine or propulsion noise. Furthermore, audible range can be divided into segments called octave bands (measured in Hz) which are used to construct the sound level function (Equation 2.14):

$$SL(i, v) = 10 \log \left( 10^{\frac{RN(i, v)}{10}} + 10^{\frac{PN(i, v)}{10}} \right) \quad (2.14)$$

Where  $i$  is the octave band,  $v$  is the speed,  $RN(i, v)$  and  $PN(i, v)$  are the rolling noise (Equation 2.15) and the propulsion noise (Equation 2.16), respectively:

$$RN(i, v) = A_r(i) + B_r(i) \cdot \log\left(\frac{v}{v_{ref}}\right) \quad (2.15)$$

$$PN(i, v) = A_p(i) + B_p(i) \frac{v - v_{ref}}{v_{ref}} \quad (2.16)$$

Being  $v$  the speed,  $v_{ref}$  a reference speed and  $A_*$  and  $B_*$  predefined and known parameters which depend on the octave band. Finally the final sound level can be corrected by road gradient, road surface and air temperature (Kephelopoulos et al., 2012).

## 4. Internalization

Considering the internal accountancy of transportation firms, in their profit and loss account appears costs related to operational activities such as purchases of raw materials, salaries of employees, or depreciation, among others. Nevertheless, costs in environmental/social terms are not included in conventional accounts of firms and, therefore, they are beyond their control. As described in section 2, by definition an externality is outside normal market process (it is not reflected in prices). Thus, negative externalities are not considered by the transport users when they make a transport decision leading to inefficiencies in the market to the detriment of the environment (Mckinnon, 2010; Santos et al., 2010). Significant negative externalities arise from

road transportation that should be added to traditional internal cost in order to achieve a full fair cost: the cost to society is greater than the one that is paid. By internalizing them, transport users will take into account such effects in their decision making process and they would be measured and controlled.

Researchers and policy developers are strongly interested in internalization of road transportation externalities. For example, [Bickel et al. \(2006\)](#) assessed the external cost of transportation internalizing it through taxation. Therefore, vehicle and fuel types, routes, scheduling, fuel types, etc. are decision which affects to both economic and environmental objectives which have to be considered to reduce the environmental impact without losing competitiveness.

#### *4.1. Pricing*

Internalization aims to correct this anomaly by increasing the price of transport services proportionally to social and environmental costs caused ([Baublys and Isoraite, 2005](#)). For this reason, setting an appropriate value on the external costs of freight transport is essential to their internalization. However, the main drawbacks when internalizing externalities is quantify them in monetary units. Finding accurate and reliable cost estimates for negative externalities is complex, and it requires a large amount of data and a good deal of subjective judgment.

Nevertheless it can be assigned monetary values in many different ways. A general first classification can be made between techniques that assess the damage caused to the environment and those that try to evaluate the cost of avoid such damage.

#### *4.2. Estimating the cost of environmental damage*

It is also known as the Damage Function Approach ([Adamowicz, 2003](#)) in which it is assumed that the damage has already been done. The problem is that, in most cases, this damage is not directly observable. Impact Pathway Approach ([European Comission, 2003](#)) tries to avoid this disadvantage by following a scheme (the pathway) that begins with the calculation of emissions from logistic activities, which you can make with the models previously reviewed. Then it traces its spread and, in the case of gases, chemical conversion and concentration at different spatial scales. The next step is a review of the receptors response (i.e. people, animals, vegetation, physical objects ...) to these emissions. These responses will normally be negative, representing a loss of welfare. Finally, losses are quantified and translated into monetary values.

There are generally two methods in order to derive these values ([Mitchell and Carson, 1989](#)). The former is related to revealed preference studies in which it is inferred an environmental cost

from current changes in people's behavior. And the latter is the stated preference survey, in which participants are asked for their willingness to pay in order to remove an externality (WTP) or to accept in compensation (WTA). The [Chapter 6](#) detailed describes stated preferences surveys and conducts a case study in Pyrenees.

#### 4.3. Estimating the cost of avoiding environmental damage

The other approach is to evaluate the cost of avoid such environmental damage. Frequently, the objective is to reach an acceptable minimum rather than eliminate the environmental effect completely. It requires an establishment of that acceptance minimum (it could be, for example, a level of CO<sub>2</sub>). Actually, [DEFRA \(2007\)](#) assumes the concentration of CO<sub>2</sub> in the atmosphere will be limited to 550 ppm by 2050.

[Table 2.2](#), based on [Mckinnon \(2010\)](#), summarizes techniques to price environmental damage from road negative externalities:

Table 2.2. Pricing environmental damage. Techniques.

Externality	Cost Element	Valuation techniques
Air pollution	Medical treatment	Health care costs
	Value of statistical life/years lost Personal suffering	Labor output
	Loss of agricultural output	WTP/WTa analysis
	Loss of landscape value	Agricultural surveys
Noise	Medical treatment	WTP/WTa analysis
	Personal suffering	Agricultural surveys
	Loss of amenity	WTP/WTa analysis
	Building value loss/repairs	WTP/WTa analysis
	Sound-proofing	Sound-proofing cost

Finally, the most widely accepted way to internalize those cost is applying the '*polluter pays principle*' what means that costs of pollution should be paid by the agent who makes profits from the process that causes such pollution. This principle requires that any entity recompenses all agents who suffer from the environmental damage. This leads to concepts such as '*green taxes*' that stands for taxes whose main objective is the conservation and protection of the environment. It would generate extra revenues that could be spent on preservation and maintenance of natural resources. Moreover, by applying '*green taxes*', a promotion and encouragement of searching for new technologies with less negative environmental impacts would be achieved ([Krass et al., 2013](#)).

## 5. Conclusions

In this review, firstly, it has been defined the freight transportation externalities and it has been identified those which are more suitable to be taken into: air pollution, noise pollution and GHG. Secondly, several models has been discussed which allow to measure the externalities previously identified. Thirdly, internalization has been considered as a way of correcting an inefficient market and pricing methods were draws as essential to valuate externalities in monetary terms.

From the literature review, some gaps has been identified for the future directions of the research. Those are the following:

- First, multiobjective optimization can be enhanced to identify tradeoffs between environmental and economic objectives.
- Second, transferring environmental concerns to other logistics activities: for example in facility location problems, relocations may lead to reductions in environment impacts.
- Third, development of a general and synthetic environmental impact model. In this sense, [Saharidis \(2015\)](#) developed an environmental externalities score model but it is neither not comprehensive nor easy-to-apply enough. Analytic hierarchy process (AHP) would be a good technique to solve general environmental impact VRP which could take into consideration a wide range of factors (cost, noise, air pollution, noise pollution...) with accurate and systematic weightings.
- Four, going deeply on pricing techniques. An efficient, comprehensive, objective, and fair way to price is required. Economics concept such opportunity cost could be explored.



## CHAPTER 3.

# HORIZONTAL COOPERATION IN FREIGHT TRANSPORT: CONCEPTS, BENEFITS AND ENVIRONMENTAL CHALLENGES



*ince its appearance in the 1990s, horizontal collaboration (HC) practices have revealed themselves as catalyzers for optimizing the distribution of goods in freight transport logistics.*

*After introducing the main concepts related to HC, this chapter offers a literature review on the topic and provides a classification of best practices in HC. Then, it is analyzed the main benefits and optimization challenges associated with the use of HC at the strategic, tactical, and operational levels.*

*Emerging trends such as the concept of 'green' or environmentally-friendly HC in freight transport logistics are also introduced. Finally, the chapter discusses the need of using hybrid optimization methods, such as simheuristics and learnheuristics, in solving some of the previously identified challenges in real-life scenarios dominated by uncertainty and dynamic conditions.*

This chapter is based in the following research contribution:

Serrano-Hernandez, A., Juan A.A., Faulin, J. and Perez-Bernabeu E. (2017) Horizontal collaboration in freight transport: concepts, benefits, and environmental challenges. *Statistics and Operations Research Transactions (SORT)*, 41(2): 393-414



## 1. Introduction

Terms such as ‘joint venture’, ‘network’, ‘alliance’, ‘coalition’, ‘cooperation’, ‘agreement’, or ‘partnership’ are frequently used in modern business activities. Due to their relevance, they are often accompanied by the ‘strategic’ adjective. Specifically, the concepts of ‘cooperation’ and ‘collaboration’ are occasionally used as synonymous by some authors (as it will be the case in this chapter), while others consider that the latter extends the former by also including mutual trust, a higher stage of commitment, etc. Several researchers have tried to rank these terms, obtaining different results depending on the economic sector and criteria considered (Mentzer, Foggin and Golicic, 2000; Golicic, Foggin and Mentzer 2003). As Barratt (2004) concluded, “cooperation is an amorphous meta-concept that has been interpreted in many different ways”. According to Hammant (2011), 95% of the companies surveyed implemented some type of collaboration strategy. However, as pointed out by Raue and Wieland (2015), misunderstanding of a collaboration agreement can lead to problems in the inter-firm relationship derived from unmet expectations from one of the sides. On the one hand, inter-firm agreements imply maintaining an independent legal personality while, on the other hand, they also entail the establishment of formulas, protocols, and frameworks that enable the collaboration in some business-related areas: finance, new product development (NPD), research and development (R&D), marketing, logistics and transportation (L&T), etc. Therefore, multiple variants of collaboration practices can occur in these areas. Table 3. classifies some representative works that offer general overviews on the concept of collaboration in different areas, including Marketing, R&D, NPD, and different variants of L&T.

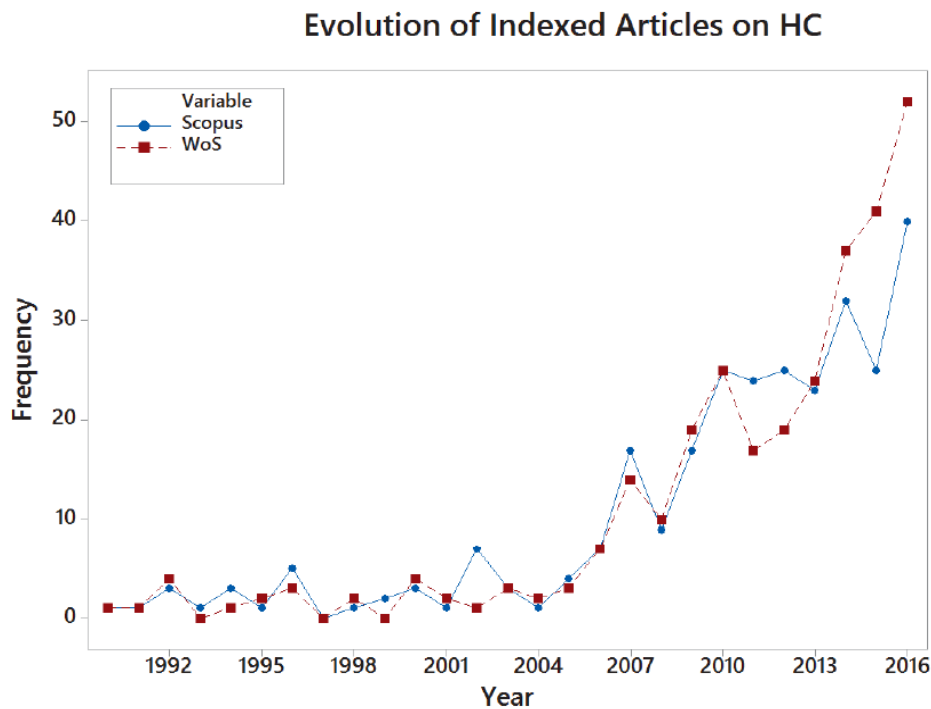
Table 3.1. Well-known works providing general overviews on collaboration practices.

	Unrelated	Vertical	Horizontal
Marketing	Rokkan et al. (2003)	Zhang et al. (2013)	Czernek, K. (2013)
R&D	Teirlinck and Spithoven (2013)	Sheng et al. (2015)	Roijakkers and Hagedoorn (2006)
NPD	Yam and Chan (2015)	Petersen et al. (2005)	Chen (2005)
L&T	Maritime	-	Álvarez-San Jaime et al. (2013a)
	Aviation	-	Álvarez-San Jaime et al. (2013b)
	Landside	-	Kuchinke and Sickmann (2005)
		Bahinipati et al. (2012)	This chapter

Companies involved in collaboration practices might be related somehow: for example, they might belong to different levels in a supply chain (vertical collaboration) or to the same level in different supply chains (horizontal collaboration or HC). In vertical collaboration, or supply chain management (SCM), agreements take place among companies belonging to different levels inside

a supply chain (Chopra and Meindl, 2007). On the contrary, HC refers to joint actions performed by several companies working at the same level of the supply chain and oriented to obtain an enhanced performance in terms of economic and ecologic impact (Bahinipati, Kanda and Deshmukh, 2009). Lambert, Emmelhainz and Gardner (1996) defined HC as a tailored relationship that is based on mutual trust and openness, with the aim of obtaining a competitive advantage – that is, assuming that conjoint performance is higher than the one each partner would achieve on its own. Cruijssen et al. (2007b) consider HC to be an interesting approach to decrease costs, improve service quality, and protect market positions. HC relies on the sharing of activities and information, which would necessarily imply sharing operation costs. Through information-sharing, small and medium enterprises expect to act as if they were a large enterprise able to benefit from economies of scale. However, sharing information implies mutual trust, which uses to be a major drawback in most HC practices (Zeng et al., 2015). Vertical collaboration inside supply chains has been intensively studied in the literature (Soosay and Hyland, 2015). There are also studies related to inter-modal transportation, establishing collaborations between truck and ship operators to provide inter-modal services (Saeed, 2013; Lopez-Ramos, 2014). As noticed by some authors (Leitner et al., 2011), the scientific literature related to HC practices is still scarce in comparison with the one dedicated to vertical collaboration, especially in the L&T field.

Figure 3.1. Evolution of indexed publications related to HC in L&T.



Despite this, during the last decade there has been an increasing interest among researchers in analyzing HC practices in L&T. This trend can be observed in Figure 3., which shows the historical evolution of Scopus- and WoS-indexed articles related to the concept of HC in L&T.

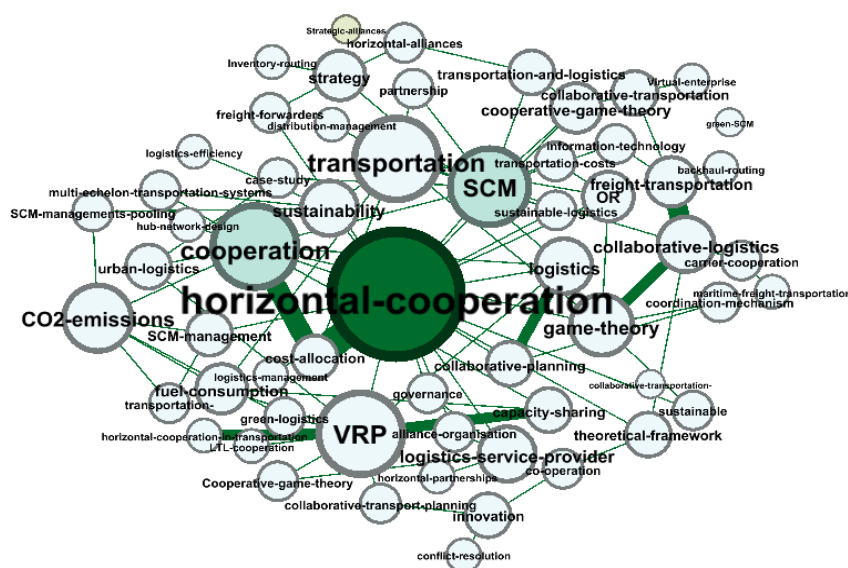
This chapter aims at partially close this gap in the literature on HC by providing the following contributions: *(i)* it offers an updated literature review on the topic and provides a classification of best practices in HC; *(ii)* it analyses the main benefits and optimization challenges related to the use of HC at the strategic, tactical, and operational levels; *(iii)* it introduces the concept of environmentally friendly, sustainable, or ‘green’ HC (GHC) in freight transport logistics; and *(iv)* it discusses the need of using hybrid optimization methods, such as simheuristics and learnheuristics, in solving some of the previously identified challenges in real-life scenarios dominated by uncertainty and dynamic conditions. To construct this survey, an intensive search was carried out in Scopus and Web of Science. In this search, the following terms were used: “Horizontal cooperation”, “Horizontal collaboration”, “coalition”, and “alliance”. The search was limited by using keywords such as “logistics”, “transportation”, and “carrier”. In addition, recent articles from well-known authors in the area of HC were analyzed in order to complete our set of paper. All in all, a total of 175 references were analyzed. With this respect, a keyword map is presented in Figure 3.2 with frequent keywords and their relationships. In that map, made with Gephi software (<https://gephi.org/>), stronger connections are represented with wider edges meaning co-occurrence of keywords. That is the case of ‘horizontal-cooperation’ keyword that usually appears in papers together with ‘cost-allocation’ keyword.

The remaining of this chapter is structured as follows: Section 2 offers an updated literature review on HC practices; Section 3 offers a classification of HC practices; Section 4 discusses potential benefits of HC at the strategic, tactical, and operational levels, respectively; Section 5 analyses the emergent research field of GHC; Section 6 proposes the use of simheuristics and learnheuristics algorithms for optimizing HC practices in real-life scenarios; finally, Section 7 summarizes the main findings of this work and outlines some future research lines.

## **2. Literature review on HC concepts**

This section offers an exhaustive review of existing works on horizontal collaboration. In order to improve its readability, the review has been organized in the following two subsections: groundworks on horizontal collaboration and works discussing its benefits and challenges.

Figure 3.2. Keywords map showing intertwined links between horizontal cooperation concepts



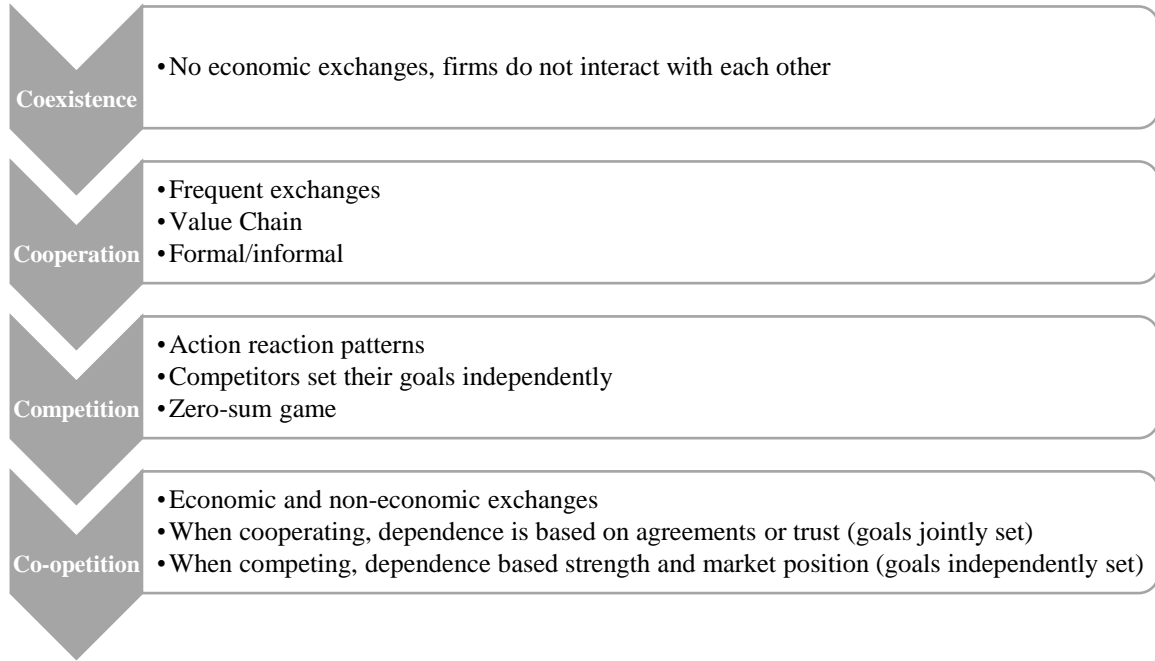
### 2.1. Groundworks

In their work related to the grocery sector, **Caputo and Mininno (1996)** are among the first authors in addressing HC in L&T. these authors highlighted the potential benefits that “cooperation between institutions placed in the same level” could provide. Before 2006, only a few publications explicitly refer to HC in the land-side transportation. Table 3.2 lists those publications and briefly summarizes their main contributions to the HC field. A turning point took place around 2007, when the topic became much more popular. Distinguished works, such as the ones by **Crujssen et al. (2007b, c)**, boosted HC and laid the groundwork for upcoming research. Afterwards, the remarkable article by Ballot and **Fontane (2010)** was published, being the first paper that clearly discussed the environmental impact associated with HC policies. As suggested in **Bengtsson and Kock (1999)**, HC may arise due to trade-offs between cooperation and competition (Figure 3.3).

Two or more companies are ‘coexisting’ when there are no economic exchanges, i.e., they are neither competing nor cooperating. A ‘pure cooperative’ scenario takes place among non-competing companies which aim at increasing their value chain through cooperation. A good example is presented in [Hsu and Wee \(2005\)](#), where two non-related manufacturers share information about production, inventory, and delivery in a stochastic environment with the aim of reducing risks. [Schmoltzi and Wallenburg \(2011\)](#) list six different factors of cooperation: contractual scope (type of agreements used), organizational scope (number of participant partners), functional scope (contributors for each functional area), geographical scope (where it will work), service scope (which services are offered), and resource scope (corporate characteristics of each partner). ‘Competition’ arises among companies focused on the same target group. Relationships among competitors are based on action-reaction patterns, and they involve

a limited information flow. ‘Co-opetition’ occurs when HC is jointly developed by competing firms. Trust and commitment become key elements to achieve fruitful relationships while keeping competition. In the L&T sector co-opetition is probably the most usual context (Limoubpratum, Shee and Ahsan, 2015).

Figure 3.3. Horizontal relationships among enterprises, based on Bengtsson and Kock (1999).



## 2.2. Works discussing benefits and challenges of HC

Reducing transportation costs is one of the most pursued goals in HC. However, many other benefits may be achieved: for example, improving service quality, diminishing environmental impact, reducing risk, and enhancing market share. Table 3.3 shows relevant references covering some of the previous purposes. The existing literature also contains experiences describing the use of HC practices in non-profit associations, as in Schulz and Blecken (2010). These authors try to adapt HC practices to disaster relief logistics, describing both benefits and issues related to these practices. According to them, the main challenges when implementing HC strategies are related to (i) how to establishing mutual trust among cooperating firms; and (ii) how to achieving a fair redistribution of both costs and profits among the partners. Due to their complex nature, HC practices offer high potential for conflicts or disagreements (Raue and Wieland, 2015; Wallenburg and Raue, 2011; Adenso-Diaz, Lozano and Moreno, 2014). Difficulty to find a suitable partner is another issue when dealing with HC (Lambert et al., 1999). On the one hand, a good knowledge of the potential partners’ assets is required to evaluate the candidates. On the other hand,

companies must share a common goal. A survey on profits / costs allocation is provided in Guajardo and Ronnqvist (2016), whereas Liu et al. (2010) focus on the less-than-truckload segment. These authors review over 40 different methodologies to share costs and profits in a coalition. However, as noticed by Yengin (2012), the Shapley's method is the most recurrent approach in the literature due to its clarity and simplicity. Table 3.4 summarizes recent references covering some of the main challenges associated with HC practices. Older references can be found in Cruijssen (2005), Cruijssen et al. (2007b), Cruijssen et al. (2007c) and Pomponi et al. (2013).

Table 3.2. Initial works covering horizontal collaboration.

Article	Contributions to the HC field
Caputo and Mininno (1996)	Propose policies to take advantage of HC in the grocery sector: order management, inventory management, warehousing handling, packaging, and transportation.
Lambert et al. (1996)	Propose a partner-selection model to build horizontal alliances. Define different cooperation types based on facilitator and driver points from surveys.
Zinn and Parasuraman (1997)	Define a framework and a taxonomy to deal with horizontal relationship in logistics activities based on scope and intensity. Discuss the concepts of integrated, extensive, focused, and limited logistics alliances.
Bengtsson and Kock (1999)	Define a framework and describe four types of horizontal relationship that companies might have: coexistence, competition, cooperation, and co-opetition.
Lambert, et al. (1999)	Implement a partner selection model in logistics.
Lau and Liu (2000)	Propose a solving procedure for an inventory management problem and a vehicle routing problem with time windows in a collaborative environment.
Bahrami (2002)	Discusses the possibility of considering HC within supply chains as an option to increase productivity. It shows a real case of two German companies that merged their distribution network, comparing a traditional situation against two alternative HC scenarios (one preserving the current logistics network and other modifying it).
Golicic et al. (2003)	Describe a series of focus-group practices aimed at discussing and identifying interorganizational relationships. A chaotic paradigm of cooperation is presented as a result of the variety of opinions.
Barratt (2004)	Identifies elements of collaboration (joint decision making, supply chain metrics, etc.) as well as the consequences of misunderstanding cooperation concepts.
Hageback and Segerstedt (2004)	Propose HC in rural areas as a way to stop depopulation.
Groothedde, et al. (2005)	Quantify economies of scale achieved through cooperation
Krajewska and Kopfer (2006)	Explain how to perform HC practices between partners having similar characteristics. Propose a model that includes the re-distribution of profit. The model is based on the combinatorial auction theory and on game theory.

Table 3.3. Main HC goals in the scientific literature.

Objectives	Discussed in
Reducing transportation costs	Soysal et al. (2016); Fernández et al. (2016); Bottani et al. (2015); Vornhusen et al. (2014); Verdonck et al. (2013); Audy et al. (2012)
Improving service quality	Ghaderi et al. (2016); Lehoux et al. (2014)
Reducing environmental impact	Danloup et al. (2015); Perez-Bernabeu et al. (2015); Juan et al. (2014); Pan et al. (2014); Pradenas et al. (2013); Peetijade et al. (2012);
Reducing risk	Stojanovića and Aas (2015); Li et al. (2012); Bahinipati et al. (2009)
Protecting/enhancing market share	Wei et al. (2015); Gou et al. (2014)

Table 3.4. Main HC challenges discussed in the scientific literature.

Impediments	Discussed in
Difficulty to ensure relationships based on trust	Zeng et al. (2015); Raue and Wieland (2015); Schmoltzi and Wallenburg (2012); Wilhelm (2011)
Difficulty to find suitable partners	Ayadi et al. (2016); Dao et al. (2014); Raue and Wallenburg (2013); Audy et al. (2012); Asawasakulsorn (2009); Bahinipati et al. (2009).
Difficulty to share profits/losses: cost allocation	Guajardo and Rönnqvist (2016); Kimms and Kozeletskyi (2016); Guajardo and Rönnqvist (2015); Defryn et al. (2015); Karsten et al. (2015); Vanovermeire et al. (2014); Lozano et al. (2013); Frisk et al. (2012); Dai and Haoxun (2012); Liu et al. (2010); Massol and Tchong-Ming. (2010); Dai and Haoxun (2015); Frisk et al. (2010); Xu et al. (2009);

### 3. Classification of HC practices

Several criteria have been proposed to classify HC practices. In this chapter, we focus on the taxonomies proposed by [Zinn and Parasuraman \(1997\)](#), [Lambert et al. \(1999\)](#), and [Pomponi et al. \(2013\)](#) since they offer complete and easy-to-implement classification systems. In order to compare these taxonomies, some common factors and levels have been identified in Table 3.5.

The main factors are: time frame, amplitude, stamina, and closeness. Time frame refers to the duration of the agreement. Amplitude refers to the level of commitment in terms of range of pooled services: for example, fleet, information, orders, warehouses, etc. Stamina is the ability of the coalition to survive by means of legal contracts, conjoint investments, etc. Finally, the organizational level denotes characteristics of the conjoint project, such as operational, tactical, or strategic ones. For each factor, three intensity levels are presented. One of the first attempts to categorize HC practices in L&T was presented in [Zinn and Parasuraman \(1997\)](#). These authors proposed a taxonomy based on the intensity and scope of the coalition. The former relates to the extent of direct involvement among allies, whereas the latter refers to the range of involved services. By combining intensity and scope, four types of cooperation arise (Table 3.6).



Table 3.5. Factors and levels to classify HC practices.

	High	Mid	Low
Time Frame	More than 3 years	Between 1 and 3 years	Less than 1 year
Amplitude	Whole company involved	Just a division	Few aspects of the company involved
Stamina	Legal contract	No contract but formal rules	Just relational rules
Organizational level	Strategic	Tactical	Operational

Table 3.6. Zinn and Parasuraman (1997) proposed taxonomy for HC

	Time Frame	Amplitude	Stamina	Organizational level
Limited	Low	Low	Low	Low
Extensive	Low	Mid	Mid	Low
Focused	Low	Low	Mid	Mid
Integrated	Mid-High	High	High	Mid- High

Another approach for classifying HC practices is provided by Lambert et al. (1996), who consider three types of cooperation (Table 3.7). Type I cooperation represents agreements in which the involved companies recognize each other as partners and coordinate their activities on a limited basis for a very short time. Type II cooperation denotes a medium-term relationship for an entire project duration and a greater level of cooperation. In contrast, in Type III cooperation firms have a high level of integration for an unlimited duration, thus involving the entire organization. In that classification, an increasing level of trust is assumed: that is, a Type I cooperation is required before a Type II one.

Finally, Pomponi et al. (2013) did not consider time restrictions and designed a framework in which cooperation is categorized based on its organizational level: operational, tactical, or strategic (Table 3.8).

As in many other areas, it is not easy to find a universal classification for all HC practices in L&T. However, this section has identified several key factors that are common in the several works and which refer to a correct understanding of a collaboration agreement in terms of duration, amplitude, legal form, and organizational level involved.

Table 3.7. Lambert et al (1999) proposed taxonomy for HC

	Time Frame	Amplitude	Stamina	Organizational level
Type I	Low	Low	Low	Low
Type II	Mid	Mid	Mid	Mid- High
Type III	Mid- High	High	High	Mid- High



Table 3.8. Pomponi et al. (2013) proposed taxonomy for HC

	Time Frame	Amplitude	Stamina	Organizational level
Operational	Low-Mid-High	Low	Low	Low
Tactical	Low-Mid-High	Mid	Mid	Mid
Strategic	Low-Mid-High	High	High	High

#### 4. Quantifying the benefits of HC in freight transport logistics

By taking advantage of economies of scale, HC practices contribute to increase firms' efficiency and competitiveness. Hence, cost reduction, improvement of service quality, and mitigation of CO<sub>2</sub> emissions are the main benefits of HC in road freight transportation. Table 3.9 summarizes recent outcomes of different research works, including the approaches adopted and their impact on costs. Notice that in some cases there is a high variability depending on factors such as the topology of the distribution network, the degree of cooperation, and the specific cooperative mechanism adopted. In those cases, a short explanation is provided as a footnote to the table. Since the existing literature presents several ways of achieving benefits depending on the decision level involved (strategic, tactical, or operational), the following subsections discuss preeminent approaches used in HC for each of these levels.

Table 3.9. Summary of recent outcomes applying HC approaches and their impact.

Strategy	Advantages	Disadvantages	Reference	Impact on costs
Tactical (conjoint routes)	It does not require a high level of integration	Revenue contracts are required.	Dahl et al. (2011)	-14%
			Wang and Kopfer (2014)	-11%
			Muñoz-Villamizar et al. (2015)	-25%
			Perez-Bernabeu et al. (2015)	-5% to -90% (1)
			Wang et al. (2014b)	-89%
			Cruijssen et al. (2007a)	-31%
			Ozener (2011)	-26 to -30% (2)
Strategic (consolidation centers)	Easily applicable	Large capital investment is required	Groothedde et al. (2005)	-14%
			Vornhusen et al. (2014)	-18%
			Verdonck et al. (2016)	-22%
			Wang et al. (2014a)	-5 to -50% (3)
			Cruijssen et al. (2010a)	-8%
Operational (improving load factors)	Easily applicable	Requires a high level of trust and commitment Revenue contracts are required	Li (2013)	-28%
			Bailey et al. (2011)	-27%
			Sprenger and Mönch (2012)	-25%
			Hernandez and Peeta (2014)	-2 to -55% (4)

(1): -5% in a clustered topology and -90% in scattered topology

(2): -26% without a mechanism of side payments and -30% with that mechanism

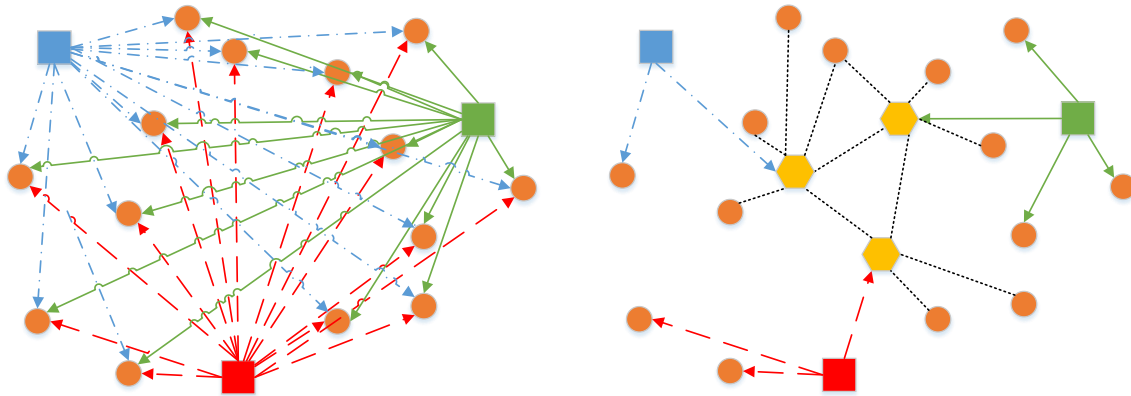
(3): -5% when companies look for a high profit margins and -50% when it is low

(4): -2% when low degree of collaboration and -55% when it is high

#### 4.1. Strategic level- consolidation center

Strategic decisions are carried out for a long-time period and involve the whole company. Determining the best location for the distribution centers of a firm is a typical example of such a strategic decision. Figure 3.4 describes an illustrative case in which firms must serve all the customers placing orders to them. In a collaborative scenario, some consolidation centers are selected to distribute products among customers in the nearby. As described in [Verdonck et al. \(2016\)](#), fixed assets such as warehouses and distribution centers can be shared in order to consolidate production from several manufactures, thus reducing the number of long-trip deliveries required. Collaborative hubs are proposed by [Groothedde et al. \(2005\)](#) to deal with a real case developed in The Netherlands. These authors also provide a methodology to assess the benefits obtained through collaboration. Transshipments, as a collaborative strategy in shared warehouses, are explored in [Vornhusen et al. \(2014\)](#). The introduction of transshipments reaches significant cost reductions when compared against isolated planning and even to centralized planning. A similar collaborative hub is proposed in [Crujssen et al. \(2010a\)](#), where a step-wise approach is formulated considering potential savings in infrastructures that require large investments.

Figure 3.4. Non-collaborative (left) vs. collaborative scenarios (right) for freight consolidation.



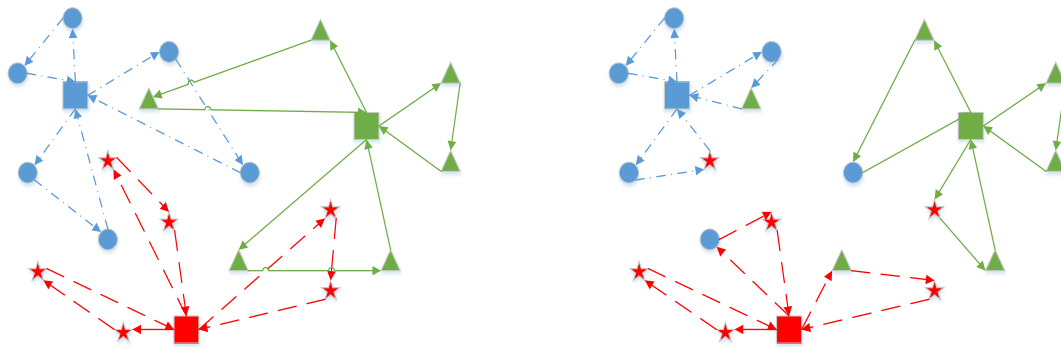
#### 4.2. Tactical level- conjoint routes

Tactical decisions are focused on the mid-term and they typically require a high level of synchronization among the departments of a firm. In this context, the use of conjoint routes emerges as the primary source of cost saving: two or more companies pool their customers to serve them from a shared depot. Therefore, clients' orders are exchanged to get a better match between customers and depots. Most articles start with a non-collaborative scenario, after which they analyze the potential benefits that could be obtained if a collaborative scenario was used instead. That is the case of [Perez-Bernabeu et al. \(2015\)](#), who compared clustered and scattered non-collaborative scenarios against the collaborative one. Similarly, [Muñoz-Villamizar et al.](#)

(2015) focused on the last mile distribution to develop a collaborative planning for carriers and assuming stochastic demands. Considering a less-than-truckload framework, Wang and Kopfer (2014) introduced a pick-up and delivery problem with time windows to illustrate HC benefits.

Similarly, Nadarajah and Bookbinder (2013) considered a two-stage framework for less-than-truckload transportation: firstly, collaboration between multiple carriers at the entrance of a city is considered; secondly, there is a carrier collaboration for transshipment to finalize the initial routes. Finally, Dahl and Derigs (2011) developed a real-time collaborative decision support system in the express carrier network. Their main purpose is assessing potential benefits obtained by sharing customers. Broadly speaking, it represents moving from several vehicle routing problems to one multi-depot vehicle routing problem, as depicted in the Figure 3.5.

Figure 3.5. Non-collaborative (left) vs. collaborative (right) scenarios for conjoint routes.

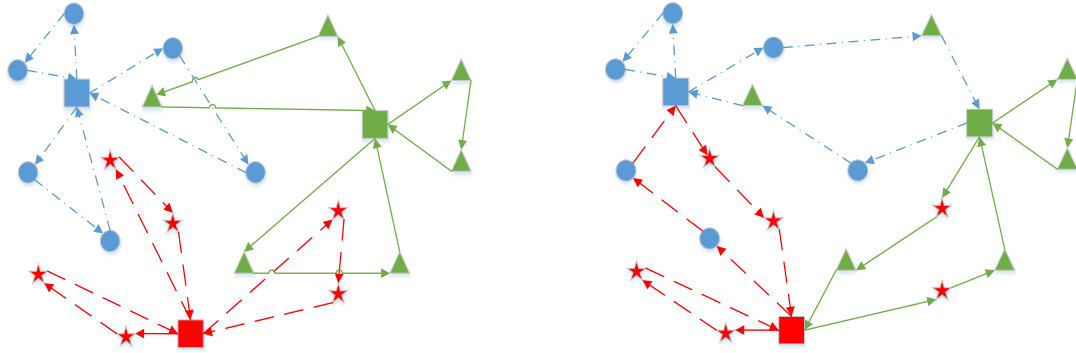


#### 4.3. Operational level- load factors

Cooperation is an efficient way to increase load factors, thus avoiding lack of efficiency in transport activities. HC approaches can help to raise these load factors in several ways, e.g.: (i) by sharing the vehicle capacity among different companies; and (ii) by employing collaborative back-hauling. As pointed out by Hernandez and Peeta (2014), sharing the vehicle capacity can significantly increase load factors, since it generates the potential to gain revenue on non-full haul trips. These authors run several sensitivity analyses based on the degree of cooperation and fuel prices. In a similar way, Sprenger and Monch (2012) discussed the concept of vehicles sharing within a German food industry. They also proposed a methodology for a collaborative transportation planning problem in a rolling horizon setting. For this problem, they used simulation to characterize the dynamic and stochastic transport system. Usually, customers are widespread over the geography, which generates long empty back-hauls after deliveries. Thus, load factors can be easily improved by collaborating to reduce empty back-hauls when companies share their logistics operations (Figure 3.6). Thus, after completing its route, a vehicle may finish in a depot different from the initial one. That is the case studied in Li (2013), who showed that

load factors could reach 92% by using such a collaborative strategy. Likewise, [Bailey et al. \(2011\)](#) investigated possible reductions in empty backhauls by considering customer requests from partners.

Figure 3.6. Non-collaborative (left) vs. collaborative (right) scenarios for back-hauling.



## 5. Environmental issues on HC

As noticed by [Allen et al. \(2017\)](#), one of the main advantages of HC practices is the reduction of the externalities associated with freight transportation. According to [Belien et al. \(2017\)](#), the main HC benefits include: (i) a 20-25% diminution in CO<sub>2</sub> emissions; (ii) a 10% improvement in transport reliability; and (iii) a 10-15% reduction in transportation cost. Following [Demir et al. \(2015\)](#), it is possible to classify these externalities into seven dimensions or impact groups: air pollution, greenhouse gas emissions, noise pollution, water pollution, traffic congestion, traffic accidents, and use of land by transport infrastructure. Despite all of these groups are relevant, air pollution and greenhouse gas emissions are likely to be the externalities that cause a higher social alarm. Green or sustainable HC refers to the use of HC practices that, by making a more efficient use of resources, contribute to reduce the environmental impact of L&T activities.

In effect, freight transport logistics generates emissions of greenhouse gases: carbon dioxide (CO<sub>2</sub>), nitrous oxide, and methane. CO<sub>2</sub> is the dominant greenhouse gas, and the remaining gases can be expressed as CO<sub>2</sub> equivalents ([Lera-López et al., 2014a](#)). Road transportation, as the primary mode of freight movement, is the largest source of freight-related CO<sub>2</sub> emissions in most developed countries. International agreements, such as the Kyoto Protocol and the Doha Amendment to Kyoto Protocol are pushing developed countries to accomplish a reduction in gas emissions. National policies have a great influence on transportation companies, which start to promote internal policies towards the development of environmentally-friendly supply chains. HC practices contribute to make the transportation sector more sustainable by means of the following policies:

- Firstly, design of conjoint routes in freight delivery, which leads to shorter distribution networks
- Secondly, sharing of responsibilities during the last-mile distribution, which allows to achieve ‘greener’ routes and to reduce the logistics activities in city centers
- Thirdly, construction of large-scale logistics scenarios, which benefit from a reduction in uncertainty –thus generating solutions involving less vehicles and routes.

As previously highlighted, the design of conjoint routes emerges as the primary source of reducing gas emissions. Insights on this topic are presented in [Danloup et al. \(2015\)](#). These authors analyzed how it was possible to reduce CO<sub>2</sub> emissions by simply increasing the loading factor of the trucks. In a similar way, [Ozener \(2014\)](#) tested an extensive set of instances to assess CO<sub>2</sub> reduction. Freight consolidation is also another driver to reach environment-friendly logistics management. As described in [Ballot and Fontane \(2010\)](#), warehouses and distribution centers can be shared to consolidate production from several manufactures, thus reducing the number of deliveries required.

Through a case study run in France, these authors showed that freight consolidation could achieve a significant reduction of CO<sub>2</sub> emissions. Another case study in France was conducted by [Pan et al. \(2014\)](#), where three different scenarios were compared to the original one in terms of CO<sub>2</sub> emissions. Internal collaboration is explored in [van Lier et al. \(2016\)](#). A summary of green HC references is displayed in Table 3.10. Again, a high variability occurs due to factors such as the distribution network topology, the degree of cooperation, and the specific cooperative mechanism adopted.

Table 3.10. Summary of recent works on Green HC.

Level	Reference	Impact on CO <sub>2</sub>
Tactical (conjoint routes)	Soysal et al. (2016)	-29%
	Danloup et al. (2015)	- 26%
	Andriolo et al. (2015)	- 50% to -26% (1)
	Perez-Bernabeu et al. (2015)	-92% to -5% (2)
	Ozener (2014)	-5%
Strategic (consolidation centers)	van Lier et al. (2014)	-6.9%
	Pan et al. (2014)	-19%
	Pan et al. (2013)	-14%
	Ballot et al. (2010)	-25%
Operational (load factors)	Basu et al. (2015)	-66%
	Pradenas et al. (2013)	-30%
	Juan et al. (2014)	-24%
	Lin and Ng (2012)	-3 to -20% (3)

(1): depending on the lot sizing policy applied

(2): -5% in a clustered topology and -92% in scattered topology

(3): depending on purchasing-of-carbon rights

## 6. Dynamism and uncertainty in real-life HC practices

The existing body of research on HC optimization mainly assumes deterministic and static models to describe freight transport systems. However, real-life optimization problems in the area of horizontal collaboration are usually characterized by properties such as large-scale dimension, dynamic conditions, and stochastic elements. In effect, since HC practices imply the aggregation of different distribution companies and their associated customers, the size of the resulting problems tends to be much larger than the one associated with any individual partner. Since several combinatorial problems in the L&T area are NP-hard in nature, the use of metaheuristic algorithms is usually required to cope with these large-scale instances. Moreover, since HC optimization problems typically consider heterogeneous enterprises and their customers, they usually offer a high degree of dynamism and uncertainty: the working conditions (and their related constraints) might be different from one company to another, the availability of shared resources might depend upon changing environmental conditions, the customers' demands might vary according to the assigned distributor or distribution time, etc. Fortunately, different hybrid algorithms can be utilized to solve rich and real-life optimization HC challenges in L&T.

Prominent examples are matheuristics that arise from integration of exact and metaheuristic methods (Doerner and Schmid, 2010), or simheuristics (Juan et al., 2015) that result from combination of simulation with metaheuristics. Different works discuss how metaheuristics can be employed to solve optimization problems under uncertainty scenarios (Bianchi et al., 2009). In particular, simheuristics allow to integrate real-life uncertainty both as part of the objective function and as probabilistic constraints in the optimization problems. Recent examples on the application of simheuristics to deal with horizontal collaboration problems under uncertainty can be found in the literature. Thus, Gruler et al. (2017) propose a simheuristic approach to optimize a waste collection problem in clustered urban areas where horizontal collaboration strategies are considered by different city managers. Likewise, Quintero-Araujo et al. (2017) propose the use of simheuristics to promote HC practices in city logistics under uncertainty conditions. Finally, de Armas et al. (2017) propose a simheuristic approach to solve large-scale facility location problems with stochastic demands –notice that this problem is strongly related to the use of consolidation centers in HC practices. In a similar way, by combining metaheuristics with statistical-learning techniques, learnheuristics allow to efficiently deal with the high level of dynamism around modern freight transport systems (Calvet et al., 2017, 2016b). Thus, for instance, in Calvet et al. (2016a) the authors propose the integration of statistical learning inside a metaheuristic framework to deal with a multi-depot distribution problem with dynamic users' demands. The ensuing models represent more accurately real-world freight transport scenarios.

Among other strengths, these hybrid methods accommodate elements of uncertainty (stochastic factors) and dynamism (evolving environmental conditions). As solution methods and techniques grow rapidly in complexity, scale, and scope, and they can easier find their way in solving more practical instances across a number of fields, a further emergence of sustainable and green HC problems considering complex multi-objective functions and probabilistic constraints is warranted.

## 7. Conclusions

As analyzed in this chapter, horizontal cooperation (HC) practices represent an efficient way of reducing costs in freight transport logistics and promote environmentally friendly policies. For that reason, the analysis of ‘green’ or sustainable HC practices is gaining importance in the recent literature. By using sustainable HC in freight transport logistics, small-size carriers may not only achieve greater economies of scale –thus increasing their competitiveness levels in a global market–, but also contribute to minimize the environmental impact of their business activities. Trust-related issues among companies, as well as difficulty to allocate costs and profits among partners are the main barriers to implement HC practices in real-life scenarios.

In this chapter, a classification of HC activities has been provided, as well as an analysis of the benefits and challenges that HC practices can provide at each decision-making level: strategic (consolidation centers), tactical (conjoint routes), and operations (load factors). Since these practices often imply solving combinatorial optimization problems characterized by a large-scale dimension and the existence of stochastic / dynamic conditions, the use of hybrid algorithms (e.g., simheuristics and learnheuristics) is proposed as one of the most efficient ways to cope with rich and real-life HC optimization problems. The emergence of new optimization methods, as well as the continuous increase in computational power, allow to consider several research lines for the future, including: (i) the inclusion of multiple goals (e.g., monetary, environmental, sustainability indexes, etc.) in the function to be optimized; and (ii) the modeling and solving of realistic freight transport logistics scenarios including time-evolving and stochastic inputs (e.g., dynamic availability of shared resources, variable customers’ demands depending on the assigned carrier, etc.).





**PART III**

**RESEARCH ON HORIZONTAL  
COOPERATION**



## CHAPTER 4.

# THE ROLE OF HC TO IMPROVE SERVICE QUALITY IN LAST-MILE DISTRIBUTION

*H*orizontal Cooperation has revealed itself as a new catalyzer for goods distribution optimization in order to achieve greater efficiency. Moreover, urban distribution is facing a new paradigm as e-commerce is growing rapidly and traffic restrictions in inner cities are becoming more frequent.

*While the economic benefit derived from the application of Horizontal Cooperation has been widely analyzed by practitioners and in academia, this paper assesses the impact of Horizontal Cooperation on service quality in a business-to-business relationship.*

*An agent-based simulation model is presented to measure savings in lead times due to various Horizontal Cooperation agreements under consideration of trust related factors. Additionally, the effect of the store-wholesaler topology is investigated, providing meaningful insights on the potentials of Horizontal Cooperation. Results of computational experiments show that cooperation enables companies to reduce lead times substantially, which increases service quality and competitiveness.*

This chapter is based in the following research contribution:

Serrano-Hernandez, A., Hirsch, P., Faulin, J., Fikar, C. The Role of Horizontal Cooperation to Improve Service Quality in Last-Mile Distribution. *International Journal of Simulation and Process Modelling*, Accepted.

## 1. Introduction

Companies are facing significant challenges in their logistics activities. Growing competition due to globalization as well as increasing customer expectations regarding service quality oblige companies to be more efficient and competitive in management of distribution operations (Lukinskiy, 2017). In order to facilitate competitiveness, companies can follow cooperation strategies with others through diverse interfirm agreements. Such agreements imply, on the one hand, maintaining an independent legal personality and, on the other hand, the establishment of processes, protocols, or frameworks that enable the cooperation in business-related projects such as logistics activities. When cooperation takes place between companies that belong to the same echelon of the supply chain, it is commonly denoted as horizontal cooperation (Cruijssen et al. 2007b).

Last-mile distribution is of particular interest as it is responsible for up to 28% of total logistics costs (Roca-Riu et al., 2012). This delivery often takes place in urban environments, commonly denoted as urban distribution. The rapid development of information and communication technologies have led to new sales channels such as e-commerce (Liu, 2016), increasing urban distribution. Even though urban distribution has a key role in the economic development of cities, it has many related challenges (Taniguchi et al., 2016) as urban areas are growing rapidly. Consequently, urban transport planning is hard to handle due to the oscillation of customer demand, distances between delivery locations, and the existence of delivery routes or geographic structures which restricts economies of scale. Additionally, the progressive pedestrianization of inner cities as well as traffic restrictions due to environmental issues are making last-mile distribution increasingly unpredictable and complex. Thus, efficient urban distribution, i.e. enabling higher frequency in deliveries and shorter lead times, is a key factor for the competitiveness of urban logistics service providers.

To enhance competitiveness in urban last-mile distribution, this chapter assesses the benefits derived from the implementation of Horizontal Cooperation on service quality among three different geographical settings. Focusing on a medium-term time frame of up to three months, an agent based simulation model is developed considering agents' behavior and interdependencies between stores and wholesalers situated in an urban area. Therefore, the contribution of this work is three-fold: i) it introduces a trust-based methodology to model Horizontal Cooperation in last-mile distribution; ii) it examines the impact of trust and various topologies on Horizontal Cooperation; and iii) it discusses potentials and effects on service quality. Preliminary results were published in Serrano-Hernandez et al. (2016), however, a more detailed description of the simulation, a wider range of scenarios, and stronger results that lead to deeper conclusions are presented in this full-length paper.

The remainder of this chapter is structured as follows: Section 2 introduces related literature. The agent-based simulation is presented in Section 3, and results of the computational experiments are presented and discussed in Section 4. Concluding remarks are given in Section 5.

## 2. Literature review

Business cooperation terminology, from a theoretical point of view, is vague not only due to the difficulty of conceptualizing the phenomenon itself, but also due to the dominance of neoclassical analysis in the study of the companies' behavior (Mentzer et al., 2000; Golicic et al., 2003). As companies, in theory, are considered to have identical production functions, it is impossible to justify the existence of business cooperation. Therefore, in market analysis, company agreements are considered collusive behaviors that reduce competition and, consequently, are not taken into account as they are a threat to achieving a more efficient production structure. For that reason, as Barrat et al. (2004) concluded, *"cooperation is an amorphous meta-concept that has been interpreted in many different ways"*.

Consequently, different definitions of Horizontal Cooperation coexist since the 1990s when the concept was formally introduced by Caputo and Mininno (1996). Afterwards, several authors aimed to give more concise definitions from several points of view. Lambert et al. (1996) define Horizontal Cooperation as a tailored relationship based on trust with the goal of gaining a competitive advantage. In contrast, the European Union (2001) gives a more general definition and define Horizontal Cooperation simply as concerted practices between companies that operate at the same level in the market. In Cruijssen et al. (2007b), it is considered as a relevant strategy to decrease costs, improve service quality or protect market positions. Bahinipati et al. (2009) denote Horizontal Cooperation as a business agreement between two or more companies at the same level in the supply chain in order to achieve a common goal.

The horizontal relationships between companies may surge as a consequence of trade-offs between cooperation and competition (Bengtsson and Kock, 1999). Two or more companies are coexisting when there are no economic exchanges, i.e. they are neither competing nor cooperating. A pure cooperative scenario takes place between companies that are not competitors since they are aiming to increase their value chain through cooperation. Hsu and Wee (2005) provide an example where two non-related manufacturers share information regarding production, inventory and delivery in a stochastic environment to reduce risks. Schmoltzi and Wallenburg (2011) list six different factors of cooperation: contractual scope (type of agreements used), organizational scope (number of participating partners), functional scope (contributors according to functional areas), geographical scope (where it will work), service scope (which

services are offered) and resource scope (characteristics of each partner to join the partnership). Competition arises between companies that focus on the same target group. Relationships among competitors are based on action-reaction patterns with a limited information flow. When Horizontal Cooperation takes place with a competitor, it surges co-opetition. Trust and commitment become key elements to achieve fruitful relationships while maintaining competition. As co-opetition is the usual context in transport and logistics activities, a balanced behavior is required (Limoubpratum et al. 2015).

A taxonomy to classify Horizontal Cooperation agreements in three different types depending on the degree of trust is presented in Lambert et al. (1999). According to those authors, a ‘Type I’ relationship indicates agreements in which companies synchronize their activities on a limited basis for a very short time period. ‘Type II’ cooperation, in contrast, denotes medium term agreements for an entire project duration and a greater level of coordination, while under a ‘Type III’ cooperation, organizations have a high level of integration for an unlimited duration, which is usually formalized with contracts. Within the simulation presented in this work, these different types of Horizontal Cooperation are implemented based on a modelled trust parameter.

Reducing transportation cost is the main objective to start a coalition (Crujssen et al., 2007c). Literature shows different strategies to achieve such objective that could be summarized as conjoined routes, freight consolidation or improving load factors. With conjoined routes, companies share their customers in order to get a better assignments between customers and depots. Most articles start from an initial non-cooperative or isolated planning scenario and then turn to a cooperative planning one. That is the case of Quintero-Araujo et al. (2016), who also deal with stochastic demands through a Monte-Carlo-based simulation. Those authors show cost reductions may reach up to 7.3%. Other works assessing the impact on cost that use conjoined routes strategies are depicted in Ozener et al. (2011) or Muñoz-Villamizar et al. (2015) with a reduction in costs around 25% in both cases. In the freight consolidation strategy, firms share or set up consolidation centers that can be used as depots for all coalitors. Even though that strategy requires a high level of integration and complexity, literature describes some real cases such as the one in Groothedde et al. (2005), highlighting that a 14% reduction in costs was achieved. Similar results with related strategies were found by Vornhusen et al. (2014) and Verdonck et al. (2013). Additionally, according to Li (2013), load factors can reach more than 90% in case collaborative strategies were adopted leading to a 28% cost reduction. Sprenger and Monch (2012) as well as Bailey et al. (2011) also investigated the effect of horizontal cooperation in reducing empty backhauls obtaining a similar result of about 25% in cost reduction.

Additionally, some work focuses on the reduction of emissions. Soysal et al. (2016) achieved a reduction of about 30% in greenhouse gas emission as result of Horizontal Cooperation. The impact on service quality is rarely investigated. Ghaderi et al. (2016) study the impact on lead

times of cooperation agreements and the authors collected real-world data of various cooperations over a 14-month period. Results show significant reductions of about 31% in lead times. In contrast to our work, no simulation is employed, the use of different geographical distributions is not considered and the impact of trust is not investigated. Regarding impediments to the implementation of Horizontal Cooperation strategies, major challenges involve the trust between cooperating companies as well as decisions on how to allocate costs and profits among the partners (Guajardo and Rönnqvist, 2016; Raue and Wieland, 2015; Verdonck et al. 2016).

With regard to modelling approaches and simulation methodologies used in transportation and logistics, Longo (2012) highlights the necessity of considering sustainability within the supply chain by taking advantage of simulation techniques. The author analyses the impacts on sustainable and economic indicators of adding new units to a pharmaceutical supply chain with a high detailed simulation model. Fikar et al. (2016) provide a relevant decision support system that combines simulation and optimization to cope with coordination between public and private agents in last-mile distribution during disasters. Similarly, the case presented in Gruler et al. (2017) uses a combination of simulation and optimization to improve waste collection in urban areas. The work presented here differs from the previous ones in two main characteristics: (i) the variable measured, i.e. while most of the articles dealing with HC are focused on transportation costs, ours is about lead times as a prominent key competitive factor for business: the service quality; and (ii) the use of simulation for establishing the coalition and its evolution.

### 3. Methodology

An agent-based simulation (Das, 2016) was developed and implemented using the software package Anylogic 7.3 (AnyLogic 2017) to study the aforementioned problem settings. Therefore, wholesalers, stores, orders and vehicles are individually modelled as agents in a geographic space. Wholesalers are the agents that may cooperate in order to improve service quality for their customers, i.e. stores. Store agents are small shops in the study area with almost no stock, i.e. micro enterprises. These types of shops are typical in urban environments and usually do not have access to complete information about the wholesaler market. In the simulation, stores are assumed to employ an (s,S) inventory policy (Arrow et al. 1951). Therefore, when the inventory level falls below a minimum value, denoted by 's', the store will generate a request for a replenishment order that will restore the inventory to a target value, denoted by 'S'. This is triggered by an event in the simulation. To initialize the simulation, each store is set up with a random value for both 's' and 'S'. Using a demand function constant in quantity but randomized in ordering time, inventory levels decrease during the day to simulate sales. Transportation of products from wholesaler locations to store locations is performed by vehicle agents. Therefore, each wholesaler has its own and homogeneous vehicle fleet.

Due to last-mile distribution and stores' characteristics, it is assumed that once an order occurs, it must be delivered as soon as possible. Starting at the wholesaler warehouse, each time a replenishment is requested, an order is generated. These agent orders are processed in the wholesaler management office. Consequently, the products are loaded in the vehicles and moved to the customer site. After unloading, vehicles return to the wholesaler location. To calculate travel times and derive delivery routes, real Viennese network data is taken from [OpenStreetMap \(2018\)](#).

### *3.1. The cooperation*

The agent-based simulation model is based on various assumptions in order to allow modeling of the problem setting. Therefore, wholesalers have identical cost structures and they provide their logistics services at a given and competitive price that cannot be changed in the short-term. Homogenous products are considered. Note that those assumptions aim to allow focusing on our variable of interest, i.e. service quality. Therefore, lead times are the only determinants for a store to choose a wholesaler. A 3-month time-horizon is selected to simulate the coalition behavior in a medium time frame. During this simulated time period, wholesalers engage in forming a coalition based in various agreements as following lines will describe. Additionally, in real-world operations, stores may open or close and the coalition may evolve to more formal agreements. Likewise, new wholesalers may enter the market or existing agents may withdraw or change their cost structures. While such factors can be easily added to the simulation, based on the medium-term focus of the simulation and to facilitate comparison of results, such factors are excluded from the computational experiments.

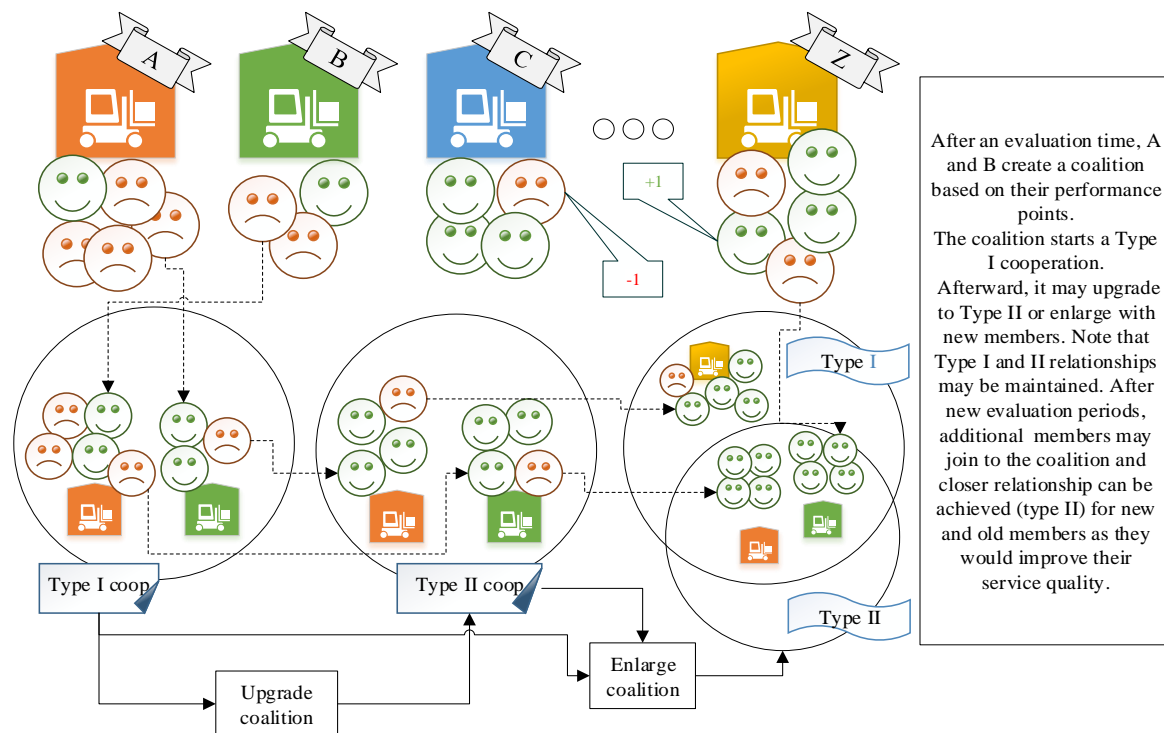
Figure 4.1 provides an overview of the following cooperative behavior in which the forklifts represent the wholesalers and the faces represent the stores. Each time an order arrives, the store evaluates the shipment regarding the achieved service quality. Therefore, a threshold value is implemented to consider the expected lead time of the store. This threshold is calculated by the best potential lead time considering the closest wholesaler and no shipping delay multiplied with a tolerance parameter. If products are delivered before this threshold, a positive performance point is given to the wholesaler, otherwise, a negative performance point is counted. Additionally, an extra point is given if the current shipment was shorter than the average lead time, otherwise, a negative performance point is considered. At the end of the working day, the wholesaler with the least performance points (the wholesaler with the weakest performance, namely wholesaler A) starts a coalition with another wholesaler in order to stay competitive. Nevertheless, wholesaler A will take some time to choose a partner to make the coalition. The partner eventually chosen (namely wholesaler B) will be someone that also has a motivation to make the coalition due to negative customer evaluations (least performance points). After this selection, A and B start a



type I cooperation to improve their respective service levels. In this context, type I cooperation implies limited information sharing about their customers in such a way that A and B maintain the same shipping volume respectively, but potentially swap customers in order to improve service levels. After another evaluation period, the coalition is assessed with two potential outcomes: i) service quality improved as a result of the coalition; or ii) service quality did not improve as a result of the coalition.

In the former case, trust in the coalition increases, and, therefore, the likelihood of raising the degree of cooperation and/or enlarging the coalition with new members will also increase. In the latter, trust in the coalition decreases, and, therefore, the likelihood of raising the degree of cooperation and/or enlarging the coalition with new members decreases. Based on the coalition trust achieved over time, a coalition potentially upgrades to a type II cooperation. In the type II cooperation, wholesalers share not only information about their customers, but also orders. This implies that a coalition acts as a single entity, pooling all the customers and assigning them to the most appropriate wholesaler. Thus, the total profit will increase, however, the distribution among the members of the coalition may differ. Therefore, as the trust in the coalition is high, it is assumed that this factor will be offset by profit-sharing agreements. Additionally, if the coalition service quality improves, other wholesalers may be interested in joining the coalition. In such a case, a type I cooperation with the coalition is started and, again, evaluated based on performance.

Figure 4.1. Overview of the cooperative behavior.



### 3.2. Geographical Scope

The model was tested with 27 wholesalers and 273 stores, which operate in Vienna, Austria. Investigation on the effect of agent locations is introduced by generating three different topologies.

- Scattered topology: wholesalers are uniformly distributed among the geographical space (Figure 4.2).
- Clustered topology: wholesalers are located in the city center (Figure 4.3).
- Segregated topology: wholesalers are segregated from the customer base (Figure 4.4) as commonly presented in real world operations where wholesalers are typically located in an industrial park outside the city center. Furthermore, in such settings, only a limited number of major transport links, i.e. bridges or highways, to connect the industrial park with the customer base is present.

Figure 4.2. Scattered topology

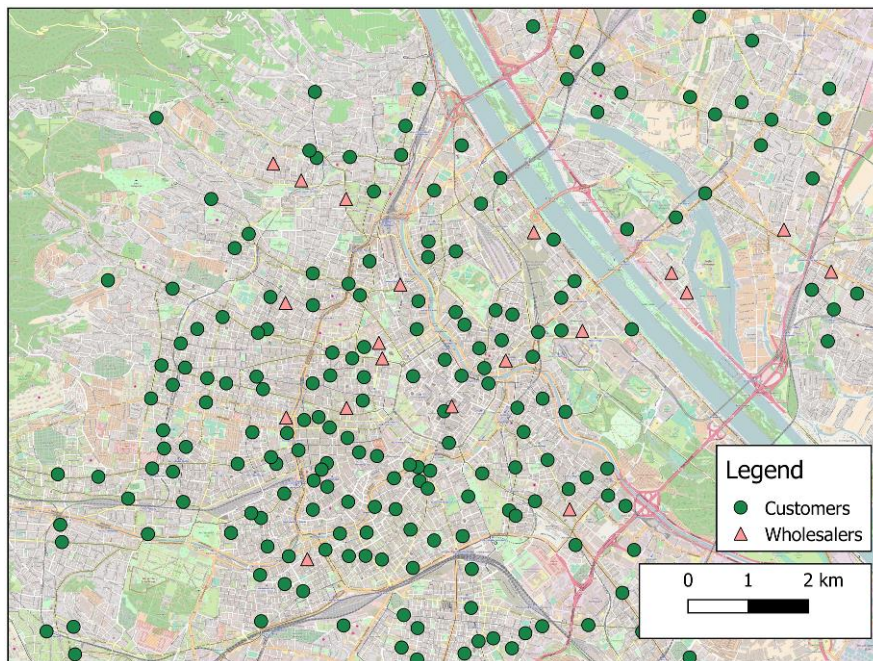




Figure 4.3. Clustered topology

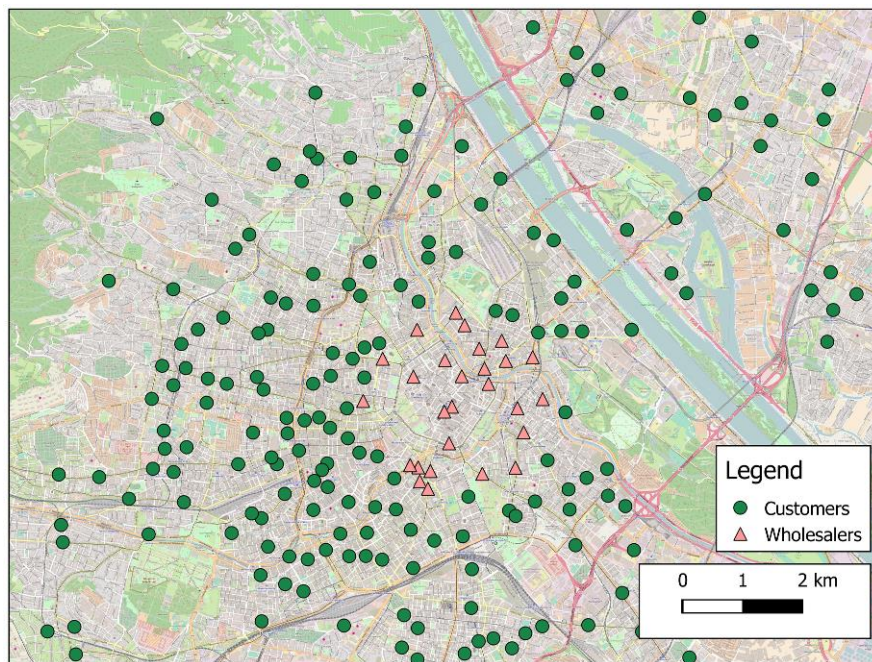
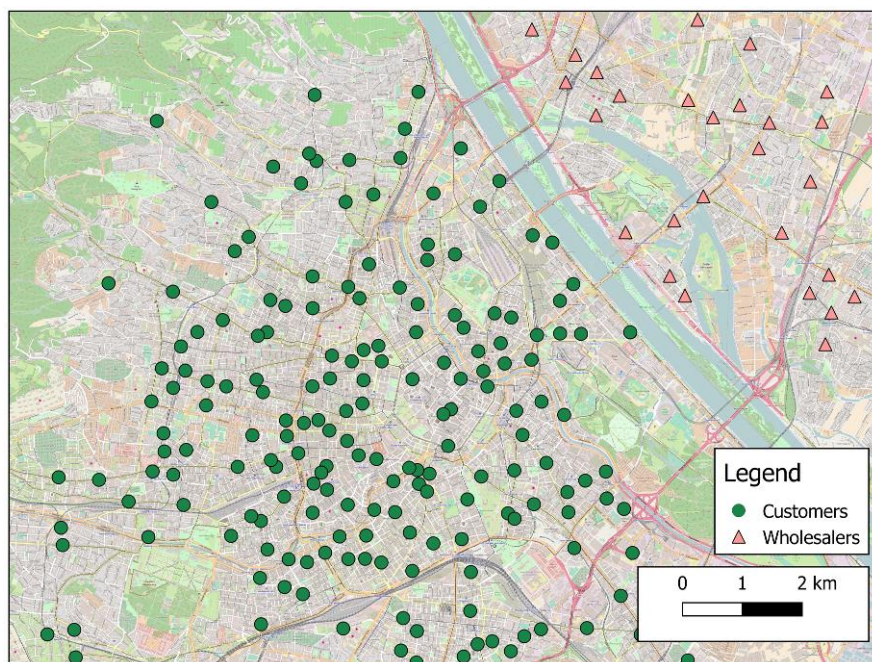


Figure 4.4. Segregated topology



#### 4. Results and discussion

Three scenarios are analyzed in order to investigate the potential effect of Horizontal Cooperation on service quality in different geographic distributions and under the consideration of trust.

- Non-cooperative: in each run, stores are randomly assigned to a wholesaler for the three-month time frame and they are not allowed to cooperate, i.e. a pure competitive setting is assumed and no information or customers are shared. Each wholesaler has its own customer base that is served if products are requested.
- Cooperation: in each run, stores are randomly assigned to a wholesaler and they are allowed to cooperate as described in the previous section.
- Full cooperation: from the beginning, stores are assigned to the most appropriate wholesaler in order to minimize lead times.

As numerical summary of the results providing absolute average lead times in minutes, are shown in Table 4.1 They correspond to the three scenarios with the three topologies based on 100 replications of the simulation experiment for the non-cooperative and cooperative settings.

Table 4.1. Average lead times (minutes) for the three scenarios and topologies

	Scattered	Clustered	Segregated
Full Cooperation	23.20	26.30	30.93
Cooperation	36.23	36.34	60.69
No Cooperation	48.09	40.73	68.73

Figure 4.5 shows the boxplots for the increase in lead times. Full cooperation corresponds to the horizontal line in which no simulation runs are required. The full cooperative scenario in the scattered topology is taken as the reference value for the other settings. Thus, percentages are computed as the increment in lead times of each scenario and topology (X) over the one obtained in the full cooperative scenario in the scattered topology (FC\_ST):  $\frac{\text{lead time of } X - \text{FC\_ST}}{\text{FC\_ST}}$ . Focusing on the full cooperative scenario, clustered topology worsens lead times by 12% whereas segregated topology worsens them by 32%. In the scattered topology, the non-cooperative scenario doubles the lead times compared to the full cooperative setting. On average, lead times in non-cooperative scenarios in clustered topology are 18% lower than in scattered settings and similar in cooperative ones. As expected, segregated topology presents the highest lead times, averaging almost three times and 1.5 times higher values than scattered full cooperative lead times in non-cooperative settings and cooperative settings, respectively. Additionally, fluctuations in the individual replications are larger when cooperation does not take place. Consequently, cooperation reduces not only lead times, but also uncertainty in delivery lead times.

Table 4.2 shows the average savings compared to the non-cooperative scenario in each topology, that is, the average reduction of leading times of each scenario and topology (X) over its corresponding non-cooperative scenario (NC):  $\frac{\text{lead time of } X - NC}{NC}$ . In all cases, cooperation allows for a significant reduction in lead times. The scattered topology is the most appropriated setting to build a cooperation since lead times may be reduced by 24%, whereas in the other two topologies, such savings are limited to 11%. Full cooperation indicates improvements in lead times if the cooperation would have been set up at the start of the simulation period, i.e. no trust issue are considered. That improvement jumps to 54% in the segregated case and 51% in the scattered case, while less savings can be achieved in the clustered topology (35%).

Furthermore, Table 4.3 shows the average savings in lead times for the full cooperation setting compared to the simulated cooperation, i.e. it quantifies the effect trust has on the potential saving that can be achieved. Similarly, percentages are computed as the average reduction of leading times of the full cooperative scenario in each topology (X) over its corresponding cooperative scenario lead times (C):  $\frac{\text{lead time of } X - C}{C}$ . As the results show, trust factors are more damaging in the segregated topology, hindering an additional reduction of 49% in lead times.

Figure 4.5. Increase in lead times against best option

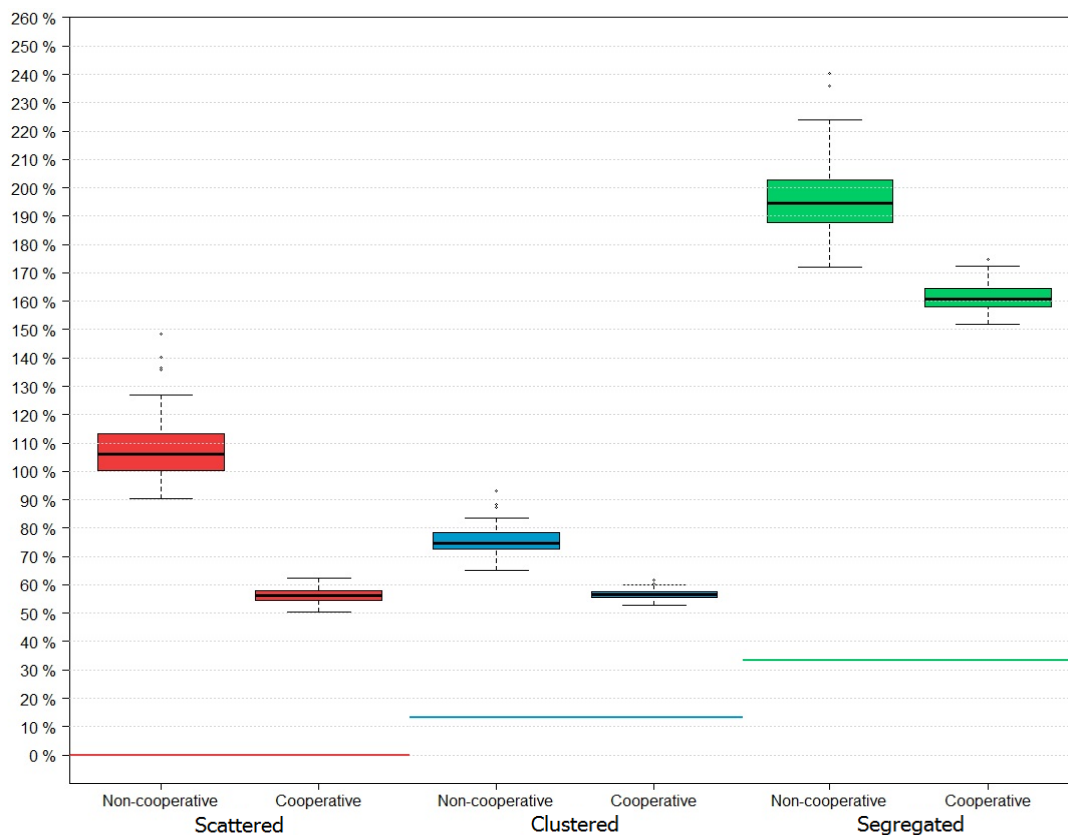


Table 4.2. Average savings in lead times against no cooperation

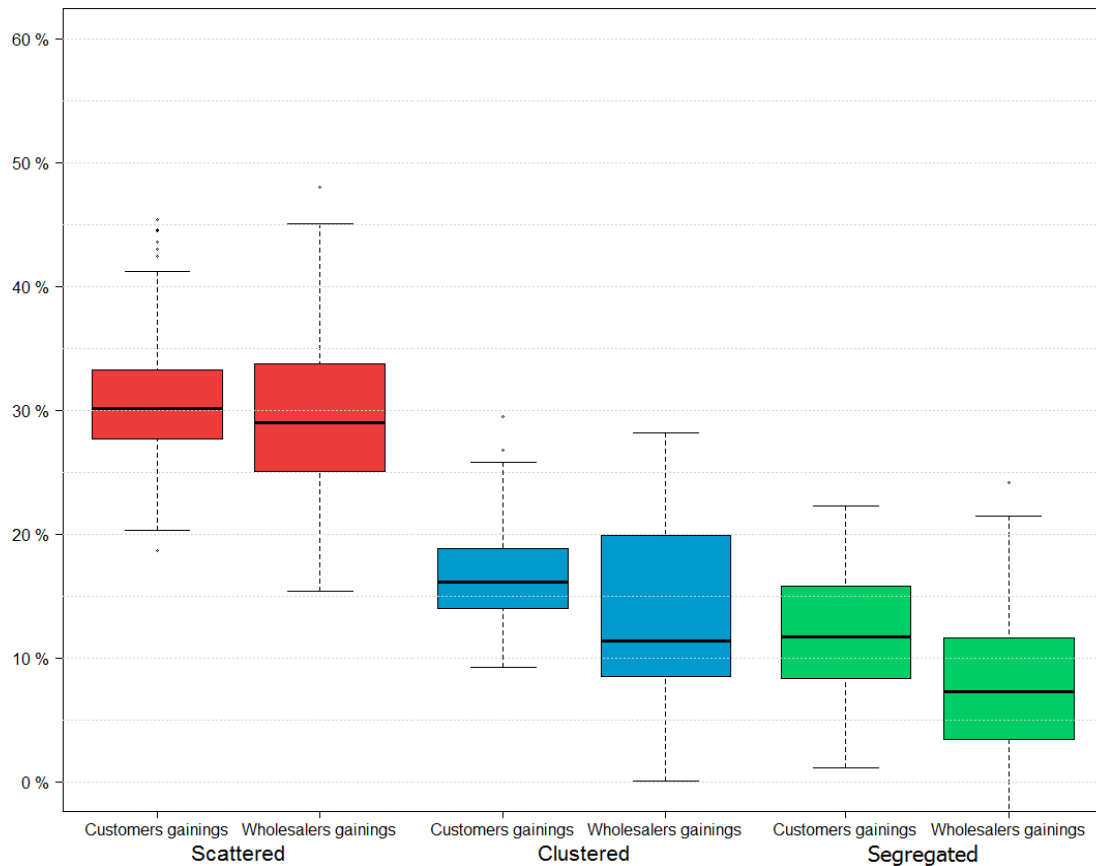
	Scattered	Clustered	Segregated
Full Cooperation	-51%	-35%	-54%
Cooperation	-24%	-11%	-11%

Table 4.3. Average savings in lead times against cooperation

	Scattered	Clustered	Segregated
Full Cooperation	-36%	-28%	-49%

Figure 4.6 shows the average savings when cooperation is enabled within the simulation process per agent and topology. Note that those savings are computed by comparing the average lead times for each agent (from customer and wholesaler point of view) before cooperation has started and after the wholesaler (and its customers) joined the coalition for the 100 replications corresponding to the cooperative setting. Scattered topology is again the most attractive setting. Average gains jump to 30% in comparison to when wholesalers are not in a coalition. On average, gains are reduced by 15% in the clustered topology. Segregated topology presents the lowest gains with 12% for stores and 8% for wholesalers.

Figure 4.6. Average savings per agent and topology.





## 5. Conclusions

Horizontal Cooperation has emerged as an important strategy that companies can adopt in order to enable greater economies of scale. This work has addressed the topic of Horizontal Cooperation from a service quality point of view in the context of urban deliveries. Therefore, lead times were used as a critical indicator of service quality in last-mile distribution. An agent-based simulation model was introduced to investigate the impact of Horizontal Cooperation on lead times in diverse topologies considering various coalition types and trust-related factors.

As shown by the computational experiments, substantial savings in lead times can be achieved if wholesalers cooperate, however, trust-related issues are a barrier to achieve greater savings. From the practical point of view, this chapter shows that cooperation is also a good strategy to improve service quality by enabling faster deliveries. Nevertheless, topology should be closely considered as it substantially affects potential savings. With the expansion of e-commerce, companies are required to take into consideration reducing their lead times to enable offering exclusive products. Consequently, as customer satisfaction and customer loyalty are, among others, key determinants to improve market position and business competitiveness (Lindgreen et al. 2012), the consideration of service quality is of high importance. Additionally, geographical distribution of stores and wholesalers have a significantly impact on potential savings in lead times due to Horizontal Cooperation, however, cooperating is still preferable in any case. A scattered topology is the most beneficial setting to engage in a cooperation. On contrary, segregated settings offer less improvements and are unbalanced concerning the savings achieved by stores and wholesalers. The trust effect is represented by comparing lead times attained in the simulated cooperation against a full cooperative scenario. As shown in the results, the lack of trust issues hinder further savings, particularly in a segregated topology.

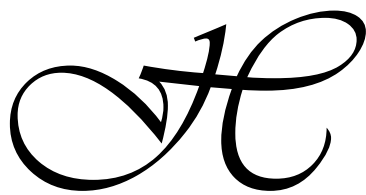
Future work focuses on additionally quantifying savings in travel costs and emissions within the simulation environment. Moreover, the consideration of extended interrelated trust factors and feedback chains in the model is planned. Furthermore, longer time frames will be investigated in different experimental settings to investigate the stability of Horizontal Cooperation in changing business environments.





## CHAPTER 5.

# AGENT-BASED SIMULATION FOR HORIZONTAL COOPERATION IN LOGISTICS AND TRANSPORTATION: FROM THE INDIVIDUAL TO THE GRAND COALITION



*Horizontal Cooperation is emerging as a way to increase competitiveness in logistics and transportation. Its implementation, however, may be hindered by conflicts and opportunist behavior among the members of the coalition. This chapter develops an agent-based simulation model studying the evolution of a coalition over time taking into account various trust-related issues. Different degrees of cooperation, rules for enlarging the coalition with new members as well as a Shapley-based methodology for allocating savings are implemented. To calculate such savings, vehicle routing solution procedures are further integrated. This enables one an extensive investigation of the effects of Horizontal Cooperation from both an economic and environmental perspective. Experimental results highlight that significant savings can be achieved with the degree of cooperation and trust related issues indicating the highest importance.*

This chapter is based in the following research contribution:

Serrano-Hernandez, A., Faulin, J., Hirsch, P., and Fikar, C. Agent-Based Simulation for Horizontal Cooperation in Logistics and Transportation: from the Individual to the Grand Coalition. *Simulation Modelling,, Practice and Theory*, under review

## 1. Introduction

Cooperative strategies are inspiring new business models towards efficiency and sustainability. Interfirm agreements allow companies to access valuable information and technology or take advantage of economies of scale, whilst, at the same time, maintaining an independent legal personality. Such business agreements normally arise as a way to seek for efficiency by reducing cost (Fernandez et al., 2016), even though other objectives can be expected such as carbon reduction (Perez-Bernabeu et al., 2015), new product developments (Yam and Chan, 2015) or advances in research and development (Sheng et al., 2015). Involved companies may be related, either inside a supply chain (i.e., vertical cooperation), along the same level of the supply chain (i.e., horizontal cooperation - HC) or not. Vertical cooperation is well documented and it is extremely related to supply chain management (SCM) (Soosay and Hyland, 2015).

Literature on HC, in contrast, is not as plentiful, particularly, within the field of logistics and transportation (L&T). Definitions of HC are provided in Lambert et al. (1996); European Commission (2001); Cruijssen et al. (2007b); Bahinipati and Deshmukh (2012).

These can be summarized as any agreement, tacit or not, which involves more than one company without vertical relationship between them, i.e., no supplier-customer relationship, based on trust and mutual commitment to identify and exploit winwin situations with the goal of sharing benefits (or risks) that would be higher (or lower) than each company would obtain if they acted completely independently (Serrano-Hernandez et al., 2016). Within L&T, reducing transportation costs is both the most pursued and investigated goal in HC (Fernandez et al., 2016). Nevertheless, many other benefits may be achieved as a result of an integrated approach such as improving service quality (Ghaderi et al., 2016; Serrano-Hernandez et al., 2016), reducing environmental impact (e.g., Lin and Ng, 2012; Pradenas et al., 2013), reducing risk (Stojanovic and Aas, 2015) and protecting/enhancing market share (Gou et al., 2014).

Table 5.1 shows selected papers addressing HC that quantifies its impacts on either costs or CO<sub>2</sub> emissions. Moreover, the organizational level in which cooperation takes place is also identified. To this respect, operational cooperation is based on sharing vehicle capacities in order to improve load factors. That is the case of the works presented by Lin and Ng (2012), Pradenas et al. (2013), and Juan et al. (2014b) who presented a vehicle routing problem with backhauling as cooperative mechanism. On the other hand, in Li (2013) cooperation is presented as a multi-depot pickup and delivery problem, and Sprenger and Monch (2012) described a real experience in the German food industry with shared vehicles. Tactical cooperation involves conjoint routes as described in Danloup et al. (2015), also in the food. Munoz-Villamizar et al. (2015) focused on the last mile distribution with uncertainty and Soysal et al. (2016) developed an inventory routing problem with many-to-many distribution centers. Finally, strategic level mainly consists on sharing consolidation centers for the long run as proposed by Verdonck et al. (2016) and

Vornhusen et al. (2014) in which it is developed a pickup and delivery problem with an exchange of customers request mechanism implemented.

Table 5.1. Selected papers employing HC and its impacts on costs and CO<sub>2</sub> emissions

Organizational Level	Reference	Costs	CO <sub>2</sub>
Operational	Sprenger and Monch (2012)	-25%	-
	Lin and Ng (2012)	-	-20%
	Li (2013)	-28%	-
	Pradenas et al. (2013)	-30%	-30%
	Juan et al. (2014b)	-16%	-26%
Tactical	Soysal et al. (2016)	-17%	-29%
	Muñoz-Villamizar et al. (2015)	-25%	-25%
	Danloup et al. (2015)	-	-26%
Strategic	Verdonck et al. (2016)	-22%	
	Vornhusen et al. (2014)	-18%	

A common characteristic of these works is their static perspective. They usually compare the setting in which companies operate independently with the situation where companies cooperate. Consequently, the development of a coalition over time as well as the evolution of the relational behavior has not been explicitly considered. Different degrees of cooperation have not been investigated and the dynamic allocation of benefits among members have been commonly ignored.

The successful implementation and operation of HC strategies over time, however, is complex. Due to their complex nature, HC practices offer high potential for conflicts, i.e., situations where two or more parties are in disagreement (Wallenburg and Raue, 2011; Raue and Wieland, 2015). To achieve the benefits that HC provides, proper management of the coalition is required to avoid lack of coordination and opportunist behavior. Raue and Wieland (2015) offer a survey on governance mechanisms to deal with cooperative and competitive relationships, identifying the most frequently used governance mechanisms: (i) operational governance through relational and formal rules and policies in order to work on a daily basis focus on enhancing trust and social identification; and (ii) contractual governance where legal parameters of the cooperation are fixed. In this regard, Adenso Diaz et al. (2014) concluded that the main factor affecting the cost synergy depends on the contractual conditions among companies. Difficulty to find a suitable partner is another common issue when dealing with HC (Lambert et al., 1999). On the one hand, a good knowledge of potential partners' assets (tangible and intangible) is required to evaluate the candidates; whilst, on the other hand, companies' interests must be met. Additionally, the distribution of costs and profits among partners as well as trust levels between cooperating firms are other common points of conflict. Concerning the allocation of profits and costs, Guajardo and

Ronnqvist (2016) provided a survey on allocation methodologies. The authors provide more than 40 methodologies to share costs and profits inside a coalition, resulting in a huge variety of arbitrary ways to divide gains and losses. Of these, Shapley value is the most recurrent methodology as it holds desirable properties such as efficiency, symmetry, and dummy (Shapley, 1953). Consequently, while recent L&T literature has paid much attention to cooperation benefits, the conflicting nature of HC has been mostly omitted or treated from a theoretical viewpoint. In contrast, this chapter contributes the scientific literature by investigating the effects of trust-related issues when running a coalition over an extended time period. Starting from a base setting in which companies operate independently, a behavioral-drive logic is modeled and implemented within an agent-based simulation framework. Leadership, negotiation processes, coalition forming and evolution in both members and degree of integration are further considered to enable a complete view on HC agreements.

## 2. Methodology

### 2.1. Model assumptions and notation

Major features of HC involve behaviors, reactions and interactions of companies involved in the agreement. Common questions of interest concern which companies start cooperating, how companies decide what information to share as well as how the trust among members evolve over time. Agent-based modeling enables one to individually model each actor in the system as well as interactions among them (Macal, 2016). Consequently, to investigate such questions present in HC, an agent-based simulation model is developed in this work. It allows one to represent behaviors, trust and reactions of various companies within a HC setting. In our work, considered agents are companies, customers and, if present, the coalition. Therefore, a coalition is any group of two or more companies that agree to work together temporarily in a partnership to achieve a common goal. Each agent class is represented with its own behavior based on variables, parameters and rules. These characteristics are described in detail in the following subsections using the notation provided in Table 5.2 Simulation is widely used in L&T given the complexity and dynamics inherent to it being a powerful tool for complex decision making processes. To this respect, Oliveira et al. (2016) made an extensive literature review enhancing the properties of modeling and simulation in a supply chain context. Naturally, simplifications are required to focusing on the important issues and removing the non-interesting parts. Moreover, given the almost unlimited concrete ways of cooperating, several aspects must be fixed and controlled to make reliable comparisons. Therefore this work is based on the following assumptions:

Table 5.2. Notation

Notation	Definition
$\mathcal{R} = \{c_1, c_2, \dots, c_R\}$	Customers set
$\mathcal{D} = \{h_1, h_2, \dots, h_D\}$	Companies set
$R_d$	Customers base of company $d$ such that $R_d \subseteq \mathcal{R}$ and $R_i \cap R_j = \emptyset$ for $\forall i \neq j \in \mathcal{D}$
$\mathcal{T} = \{1, 2, \dots, T\}$	Time set
$\mathcal{S}_t$	Any coalition such that $\mathcal{S}_t \subseteq \mathcal{D}$ and $\mathcal{S}_t \neq \emptyset$ at time $t$
$k_t$	Size of the coalition at time $t$
$v_t(\mathcal{S}_t)$	Value of the coalition at time $t$
$\phi_d$	Shapley allocation for company $d$
$dem_{cd}$	Demand of customer $c$ that belongs to company $d$
$C_0(d, t)$	Costs of company $d$ without coalition at time $t$
$C_s(d, t)$	Costs of company $d$ in coalition at time $t$
$C_t(\mathcal{S}_t)$	Costs of the coalition at time $t$
$Trust_t(\mathcal{S}_t)$	Level of trust in the coalition at time $t$
$(1 + \delta)$	Trust reward factor
$\epsilon$	Trust goodwill, context for HC application
$\xi_t(\mathcal{S}_t)$	Likelihood of enlarging the coalition at time $t$
$\psi_d$	Likelihood of company $d$ of starting a coalition
$\eta(\mathcal{S}_t)$	Tangible outcome from HC application at time $t$
$\sigma, \tau$	Synergy requirements

- Two different customer types are modeled, based on the regularity of their orders. We consider it a reasonable simplification in many industrial sectors. A detailed description of the customers is reported in Subsection 2.3.1.
- Three degrees of cooperation are modeled. Knowing that cooperation can take several realizations, we defined three reasonable cooperative behaviors following the ideas proposed by [Lambert et al. \(1996\)](#). The concrete cooperation agreements we used are detailed described in Subsection 2.3.3.
- Allocation of savings follows the Shapley methodology ([Shapley, 1953](#)). We consider Shapley value because it has many desirable properties and it is commonly used in related literature ([Guajardo and Ronnqvist, 2016](#); [Lozano et al., 2012](#)). Further information on how companies share their savings is presented in Subsection 2.3.4, including those desirable properties.
- Companies are rational and their objective is minimizing operational costs at a given customer satisfaction level. We also consider that only one coalition may exist at any time.
- Trust is formed based on savings (tangible outcome) and it is the only determinant for a company to join others and for enlarging the coalition with new members. This assumption is partly relaxed when goodwill is incorporated to the model. For simplicity,

we consider goodwill inherent to the society and it takes the same value for all companies. Further information on trust is given in Subsection 2.3.5

- There exist a given savings threshold for a company what it is worthy to cooperate. We call them synergy requirements, as initially proposed by Wang et al. (2017).
- For the measurement of CO<sub>2</sub> emissions, we only consider the distance and the payload following a given methodology described in Knorr et al. (2011). Additional information about the measurement methodology is provided in Subsection 2.3.7.

## 2.2. General framework

Our model is partly inspired by the partnering process developed by Lambert et al. (1999) in which the right combination of drivers and facilitators may result in an initial coalition, the addition of new members or a higher level of integration within the coalition. This process is shown in the Figure 5.1 Assuming that a reduction in costs is the main driver (Fernandez et al., 2016) and sufficient facilitators are given, i.e., empathy, symmetry and strategic fit (Cruijssen et al., 2007a), policies become the critical part in HC. Therefore, three different cooperative policies are defined in our work corresponding to the three levels of cooperation degree in Lambert et al. (1996). As summarized in Table 5.3, cooperation policies can be classified in Type I, Type II, and Type III, taking into account the time frame, extent of agreements and the organizational levels implied.

Figure 5.1. Partnering process in coalitions for HC, based on Lambert et al. (1999).

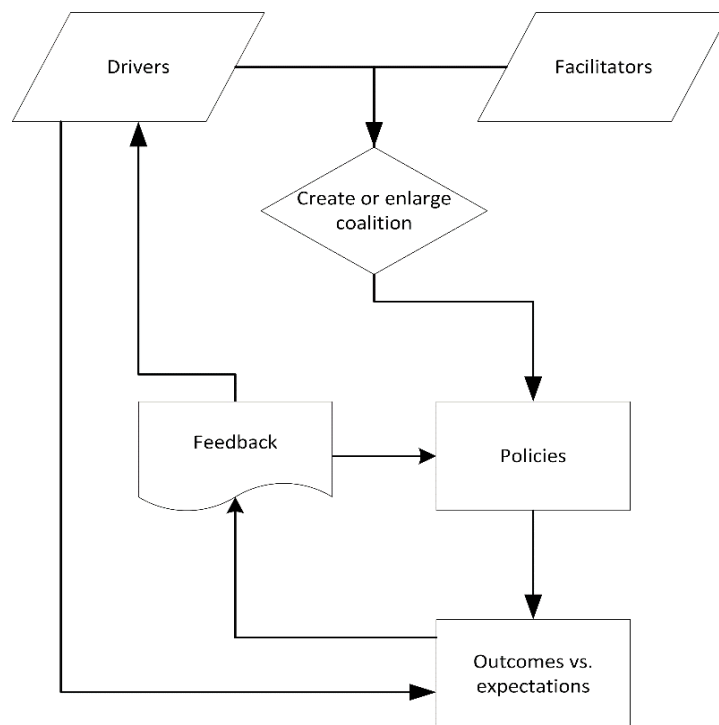


Table 5.3. Different levels of cooperation considered within the simulation framework

Type	Definition
Type I	Temporal agreement on a limited basis
Type II	Medium term relationship with a medium level of cooperation
Type III	Long-term collaboration with high level of integration

Type I Cooperation represents agreements in which involved companies recognize each other as partners and coordinate their activities on a limited basis for a very short time period. Type II Cooperation denotes a medium term relationship for an entire project duration and a greater level of cooperation. In Type III Cooperation, firms have a high level of integration, i.e., they usually act as a whole company, for an unlimited duration involving the entire organization. These types and their development over time are implemented in the simulation. Once policies are implemented, outcomes are evaluated in comparison with expectations. Those outcomes feedback the policies and/or readjust the drivers that ultimately may encourage a greater level of integration. Once such policies are implemented, outcomes are constantly evaluated and compared with the expectations of each member. This triggers a feedback, which potentially results in readjustment of the drivers that may, e.g., encourage a greater level of integration or adding additional members to the coalition. Therefore, payoffs are based on the difference in costs between being part of a coalition and not. Given a set of companies  $\mathcal{D} = \{h_1, h_2, \dots, h_D\}$ , any coalition  $\mathcal{S}_t$  is defined as  $\mathcal{S}_t \subseteq \mathcal{D}$  and it is any subset from all subsets of  $\mathcal{D}$ , i.e.  $\mathcal{S}_t \in \mathcal{P}(\mathcal{D})$ , such that  $\mathcal{S}_t \neq \emptyset$ ; at any time  $t$ . The value of the coalition  $v_t(\mathcal{S}_t)$  at time  $t$  is computed as the accumulation of all payoffs obtained from companies in the coalition, as described in Equation (5.1):

$$v_t(\mathcal{S}_t) = \sum_{d \in \mathcal{S}_t} [C_0(d, t) - C_s(d, t)] \quad (5.1)$$

Where  $C_0(d, t)$  is the individual costs of company  $d$  without coalition at time  $t$ , and  $C_s(d, t)$  is the company's cost in the coalition  $\mathcal{S}_t$ . The total costs of  $\mathcal{S}_t$  at time  $t$  is given by  $C_t(\mathcal{S}_t)$  in the Equation (5.2):

$$C_t(\mathcal{S}_t) = \sum_{d \in \mathcal{S}_t} C_s(d, t) \quad (5.2)$$

### 2.3. Model description

Given a set of companies  $\mathcal{D} = \{h_1, h_2, \dots, h_D\}$  and  $D$  subsets of customers  $R_d, \forall d \in \mathcal{D}$  such that  $R_i \cap R_j = \emptyset$  for  $\forall i \neq j \in \mathcal{D}$  and  $R_d \subset \mathcal{R} = \{c_1, c_2, \dots, c_R\}$ , the objective of each company is to serve its customer base at minimum costs. Therefore, each company solves a Capacitated Vehicle Routing Problem (CVRP) on a complete weighted graph  $G = (V, E)$ . The

vertex set  $V = R_d \cup \{P_0\}$  contains a customer subset  $R_d = \{c_{1d}, c_{2d}, \dots, c_{Rd}\}$  with each customers associated with a demand  $dem_r > 0, \forall r \in R_d$  and the company's central depot  $P_0$ , at which a homogeneous fleet of vehicles with a maximum capacity  $Q$  is sited.

The edges set  $E = (i, j): i, j \in V, i \neq j$  describes the links between two vertices, where  $dist_{ij}$  states the travel distance from vertex  $i, j$ . The objective is to find the cheapest sequence of customers such that vehicle routes start and end at the depot, each customer is visited exactly once and has its demand fulfilled, and vehicles capacities are not violated.

### 2.3.1. Customers

Two kinds of customers are modeled within the simulation:

- Loyal customers: At the beginning of each run, a given proportion  $\alpha$  of all customers are labeled as loyal. These customers are randomly assigned to a company in order to simulate the customer base and always order from the assigned company. Orders are placed each week.
- Non-loyal customers: In contrast, the other part  $(1 - \alpha)$  of customers randomly make orders over the simulation horizon and place them at a random company. Consequently, orders for each company differ from one week to the next one.

### 2.3.2. Companies

Companies are the agents within the simulation that may cooperate. Each company has a loyal customer base that must be served and a loyal market share that should be maintained. Each week companies collect the orders from loyal and non-loyal customers and solve a CVRP to find the most cost-effective delivery routes.

### 2.3.3. Agreements

The considered agreement results from the level of cooperation. Type I Cooperation follows an auction-based mechanism (Li et al., 2015) in which one company offers all their non-loyal customers for the next delivery period. This potential partner is selected based on the lowest total distance from the company's depot to the non-loyal customers. No information sharing between the two companies occurs. Consequently, it is not possible to know in advance which cost impact is expected from offering these customers. For compensation, the auctioneer offers a proportion  $(1 - \sigma)$  of the achieved savings  $v_t(d) > 0$  from not having to visit these customers. This offer is accepted by the bidder if it is greater than the cost increase  $-v_t(d') > 0$  adjusted by a factor  $\tau$ . In other words, the agreement is reached and a Type I Cooperation is set up if the value of the coalition is positive and sufficiently large, as described in Equation (5.3):



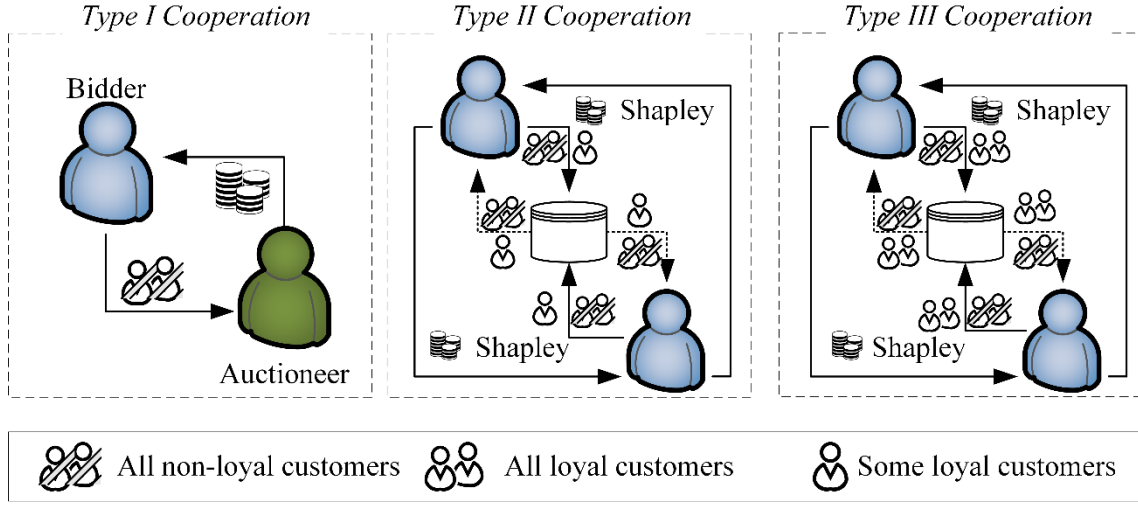
$$v_t(\mathcal{S}_t) = (1 - \sigma)v_t(d) + (1 + \tau)v_t(d') \geq 0, \quad \sigma \in [0,1]; \tau \in [0, \infty) \quad (5.3)$$

Where  $\sigma$  and  $\tau$  may be considered as a synergy requirement as accounted by [Wang et al. \(2017\)](#) and are defined as the proportion of savings a company requires in order to join coalition. We distinguish between two synergy requirements ( $\sigma$  and  $\tau$ ) to give flexibility to the negotiation process from both sides. If the first bid is not accepted, a negotiation process starts by reducing the number of non-loyal customers offered and updating the bid. As a result, in the second round, the non-loyal customer with the least marginal cost is removed from the offer. This customer is selected by solving as many CVRPs as non-loyal customers are, removing one customer each time. The non-loyal customer selected corresponds the least total cost obtained from the CVRP solutions. Consequently, this reduces both savings of the auctioneer and the cost increase of the bidder. Later conditions given in Equation 3 are rechecked. If the offer is rejected again, the negotiation process restarts by removing another non-loyal customer. If all non-loyal customers were removed and no agreement is reached, another company is selected based on the non-loyal customers' distance. In case no company accepts the offer, the negotiation process is started in the following week by a different company.

Type II Cooperation implies a higher degree of trust and commitment. As a result, loyal customers are further considered. All non-loyal customers from all members of the coalition are pooled as well as a proportion of their loyal market share. That proportion is randomly determined each time a Type II agreement is signed following a uniform distribution between [0.2; 0.4]. Consequently, each company maintains 60-80% of their loyal market share, while the remaining customers are transferred to a pool of customers. Similarly to Type I agreement, the customers to be shared are selected according to their marginal costs, however, this time the one with the highest marginal cost is considered first. An exchange request mechanism based on [Wang and Kopfer \(2014\)](#) is implemented in order to assign customers to the coalition members. That mechanism consists of multiple rounds of picking customers, which is based on marginal costs, from the pool until it gets empty. As this process does not guarantee to achieve savings, a negotiation process is further required. It consists of progressively reducing the number of shared loyal customers, similar to the negotiation process explained for the Type I agreement. If no savings can be achieved, an event to suspend the coalition is triggered within the simulation framework.

Type III Cooperation stands for the highest degree of cooperation and implies that the coalition acts like a whole firm. Therefore, all members transfer all their customers to the coalition and solve a multi depot VRP (MDVRP) in which each customer is assigned to the companies which results in the lowest total costs. A visual representation of the aforementioned agreements is given in the Figure 5.2.

Figure 5.2. Visual scheme for the proposed agreements



#### 2.3.4. Sharing the savings

For a Type I Cooperation, payoffs are computed as a result of an auction-based mechanism. In Type II/III agreements, the allocation proposed by Shapley (1953) is implemented. It allocates to each company  $d \in \mathcal{D}$  an average of the marginal costs it gets when joining the coalition as described in Equation (5.4):

$$\phi_d = \sum_{\mathcal{S}_t \subseteq \mathcal{D}: d \in \mathcal{S}_t} \left[ \frac{(|\mathcal{D}| - |\mathcal{S}_t| + 1)(|\mathcal{S}_t| - 1)!}{|\mathcal{D}|!} \right] [C(\mathcal{S}_t) - C(\mathcal{S}_t \setminus \{d\})], \forall d \in \mathcal{S}_t \quad (5.4)$$

Shapley allocation has desirable properties such as efficiency, symmetry, and dummy. Efficiency refers to a fair allocation as it divides the whole savings. It is symmetric in the sense that if two companies contribute the same to every coalition, they should have the same Shapley value, while the dummy property ensures that if a company does not contribute anything, it receives nothing. When the coalition has only two members, Shapley values are simply computed by dividing the savings by two since the coalition would disappear if a single member leaves. For a larger coalition, all different combination of intermediate coalitions have to be tested. For instance, to compute the Shapley values for a coalition made by A, B and C companies, coalitions AB, AC and BC are evaluated as well as their individual costs (A, B, C) and the cost of the grand coalition (ABC). To test these intermediate coalitions, the same process than for the Type II agreement policies are implemented as the costs of a new enlarged coalition in which the new member stays will be the aggregation of their pre-coalition costs.

### 2.3.5. The trust indicator

Trust is the basis for the evolution of the coalition from Type I to III and for enlarging it with new members. Following the partnering process described in Lambert et al. (1999), trust is gained (or lost) every time a coalition is tested for the obtained outcome. In our work, the first value for the trust indicator  $Trust_t(\mathcal{S}_t)$  is computed by two parts:

- The tangible outcome ( $\eta_t$ ) at time  $t$  from the cooperation policy application, computed as the average relative savings over the total cost of the coalition, as represented in the Equation (5.5):

$$\eta_t = \frac{v_t(\mathcal{S}_t)}{c_t(\mathcal{S}_t)k_t} \quad (5.5)$$

- The intangible part ( $\epsilon$ ), which represents the goodwill of the involved companies and it depends on the cultural and competitive context in which the companies operate. A large value of  $\epsilon$  means companies are more trusting and more willing to cooperate for other reasons than economic ones, while a low  $\epsilon$  give more importance to purely economic outcomes. Consequently, the first value of trust indicator is described in Equation (5.6), while the development over time ( $t$ ) is described by Equation (5.7). Later, a reward factor ( $1 + \delta$ ) is included to model the way trust is gained in forthcoming periods:

$$Trust_0(\mathcal{S}_t) = \min(\eta_0(\mathcal{S}_t) + \epsilon, 1); Trust_0(\mathcal{S}_t) \in [0,1] \quad (5.6)$$

$$Trust_{t+1}(\mathcal{S}_t) = \min(\eta_t(\mathcal{S}_t) + (1 - \eta_t(\mathcal{S}_t))\eta_t(\mathcal{S}_t)(1 + \delta), 1); \delta \in [0, \infty) \quad (5.7)$$

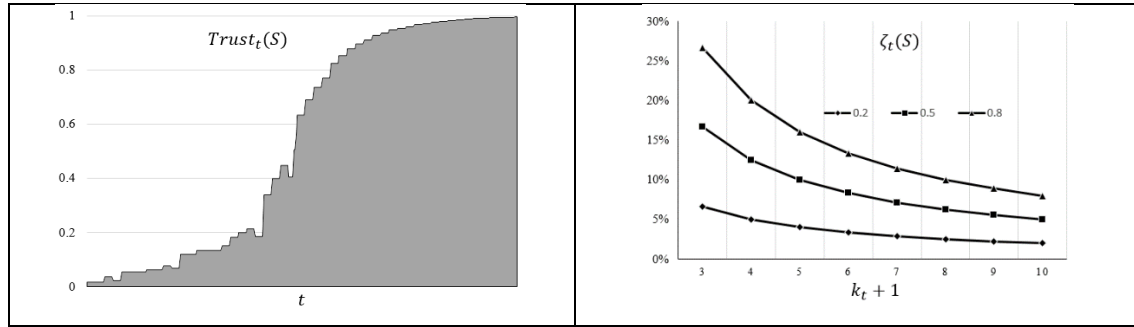
The Figure 5.3 shows an example of how  $Trust_t(\mathcal{S}_t)$  may evolve over time. This trust indicator allows upgrading the coalition and enlarging it with new members. To upgrade from Type I to Type II and from Type II to Type III, a random number  $\Theta \sim U(0,1)$  is generated and compared against  $Trust_t(\mathcal{S}_t)$ . If  $\Theta \leq Trust_t(\mathcal{S}_t)$ , the coalition successfully upgrades its level of integration. This description is in line with literature since greater savings will encourage coalition to improve their relationship which may be eventually strengthened with larger agreements (Lambert et al., 1996; Pomponi et al., 2013).

Additionally, a coalition may incorporate new members, however, only in Type II or III Cooperation and only if it results in a greater payoff for the initial members. That is justified by the Strictly Monotonic Path (SMP) discussed by Cruijssen et al. (2010b). Along such a SMP, all committed companies will be better off when the coalition grows if the next company joins the coalition. Consequently, the coalition will not accept new members if this results in lower payoffs. As enlarging a coalition may be quite difficult due to organizational issues, a double hurdle process is further implemented once the SMP conditions hold. Firstly, the trust in the coalition is tested as done for upgrading the coalition. Secondly, organizational issues are considered by

lowering the likelihood of enlarging the coalition as it grows. Therefore, the likelihood of enlarging the coalition is given in Equation (5.8), considering the target size of the coalition. The Figure 5.3 shows the likelihood of enlarging the coalition for 3-10 members for varying levels of trust.

$$\xi_t(\mathcal{S}_t) = \frac{Trust_t(\mathcal{S}_t)}{k_t + 1} \quad (5.8)$$

Figure 5.3. Trust indicator evolution: trust indicator (a) and likelihood to enlarge the coalition as a function of target coalition size and trust indicator level (b).



### 2.3.6. The sequence

In the first step, costs of loyal customers are calculated. Each company solves a VRP with its loyal customer base. Additionally, the model calculate costs if all companies are working independently. Comparison of both results allows one to know the effect of customer uncertainty on costs, which is the main driver for engaging in a coalition. Consequently, the likelihood for each company  $d \in \mathcal{D}$  to start a coalition is computed as described in Equation (5.9):

$$\psi_d = \frac{\frac{c_d - \bar{c}_d}{c_d}}{\sum_i \frac{c_i - \bar{c}_i}{c_i}} \quad (5.9)$$

Where  $c_d$  are the costs of company  $d$  concerning the loyal customers and  $\bar{c}_d$  the average costs obtained in the evaluation phase with all customers. When the agreement is reached, an initial trust indicator value  $Trust_0(\mathcal{S}_0)$  is established and that coalition is initiated. As Type I agreements are for a very short time frame, the agreement is only valid for the current delivery period. The contact made by both companies, however, will be maintained for upcoming operations in following periods and associated with a trust factor. Savings for each company are computed, payoffs collected, the value of coalition calculated and the trust indicator is updated. Over time, the same companies try to cooperate again. If no agreement was made, the trust indicator is reduced since  $v_t(\mathcal{S}_t) < 0$  until it turns negative. In that case, the contact is definitely dissolved and the process of creating a new coalition starts again with new companies.

Each time the trust indicator of a Type I Cooperation increases, the coalition may, as previously discussed, upgrade to a Type II Cooperation. If so, in subsequent delivery periods, Type II agreement policies are applied. Furthermore, each time the trust of a Type II Cooperation increases, a chance to either upgrade the coalition to a Type III or enlarge the coalition with new members is given. Upgrading the coalition to Type III Cooperation follows the same methodology than upgrading from Type I to Type II. In case the coalition does not upgrade, the double-hurdle process for enlarging the coalition takes place. Once Shapley values are obtained, Strictly Monotonic Path is checked and if the Shapley value for the new member is positive and sufficiently large (based on  $\tau$ ) the coalition is enlarged. Additionally, a mechanism to suspend the coalition is implemented. If any Shapley value turns negative, then firms operate independently ( $v_t(\mathcal{S}_t) = 0$ ), a zero Shapley value is assigned to each company in the coalition and enlarging or upgrading the coalition is disabled. If a coalition reaches Type III, no further upgrades are possible, however, the coalition can still be enlarged. Therefore, the process as introduced for the Type II Cooperation is employed.

### 2.3.7. Measuring CO<sub>2</sub> emissions

Beside the impact on costs, the performance of the individual coalitions on CO<sub>2</sub> emission is further recorded within the framework. Therefore, the methodology proposed in EcoTransIT (Knorr et al., 2011) was implemented in our model. Energy consumption is measured by megajoules and it depends on distance, payload, road slope, speed and vehicle characteristics. For any given distance, the fuel consumption ( $FC$ , in liters of diesel fuel per km) can be represented as a function of load weight where  $FC_e$  is the fuel consumption when it is empty,  $FC_f$  the fuel consumption when full loaded,  $P$  the payload in tons and  $Q$  the vehicle capacity in tons:

$$FC = FC_e + \frac{(FC_f - FC_e)P}{Q} \quad (5.10)$$

For our experiments, a standard EURO V 26-40 truck, i.e., maximum capacity of 26 tons and a curb weight equals to 14 tons, has been selected for the parameter settings. This results in  $FC_e = 0.2364$  and  $FC_f - FC_e = 0.15$  for  $0 \leq P \leq 26$  with an emission rate of 2.67 kg of CO<sub>2</sub> per liter of fuel (Coe, 2005). Capacities for the vehicle based on demand units are automatically rescaled within the simulation to match these figures.

### 2.3.8. Vehicle Routing Procedure

To derive distribution costs of each individual company, a VRP has to be solved within the HC framework. This procedure has to be run in each distribution period and further each time a new coalition option is evaluated. Consequently, a focus on execution speed was set to enable real-

time solution within the agent-based simulation. Therefore, a biased-randomized solution procedure (Grasas et al., 2017) was implemented based on the ideas presented in Juan et al. (2015), which shows competitive results, particularly on small multi-depot instance sizes as often present in HC settings where only a limited number of companies cooperate. The general idea of this procedure is to perform multiple runs of the savings heuristics (Solomon, 1987) with each run subject to some directed randomness. Starting from the setting where each customer is individually served by a vehicle, the heuristic looks for feasible pairs of customers which can be merged into a single route while respecting vehicle capacities. In our implementation, the best merge is not always selected but instead drawn from a geometric distribution favoring more promising ones, i.e., merges resulting in the highest savings. Additional information about the use of heuristic approaches within a simulation environment in L&T can be found in Juan et al. (2014a).

For settings with only one company involved, i.e., if the company is not in a coalition or in case of Type I and Type II Cooperation, this biased-randomized saving heuristic is run multiple times and the best found solution is taken to evaluate this setting. For MDVRPs, i.e., in case of a Type III Cooperation, the allocation of customers to companies is further done with a biased-randomized selection procedure. All companies involved in the coalition are sorted by distance to the individual customer. In the following step, each customer is randomly assigned with closer companies being favored. The allocation of customers to companies, which provided the lowest costs so far, is further saved and acts as a basis for the following iteration. A percentage of this allocation is kept, e.g., 75% within our computational experiments, while the remaining customers are biased-randomly assigned to a company. After a certain number of iterations, the procedure stops and provides costs and emission of the optimized vehicle routes for both the entire coalition and each individual involved company.

### 3. Experimental results

The software package Anylogic 8.0 AnyLogic (2017) is used to study the proposed HC model for a time frame of 52 weeks (1 year). The simulations were run on an Intel Core i5-3570 CPU @ 3.40 GHz PC with 8GB RAM. The parameter setting for the base scenario is as follows: a 14 weeks warm-up phase, which is not included in the 52 weeks, is run to set up the simulation and evaluate performance before starting the first coalition. Synergy requirements ( $\sigma$  and  $\gamma$ ) are set at 20%, proportion of loyal customers to 80% over all customers and the probability a non-loyal customer makes an order in any week is set to 50 %. Moreover, we have used the instance p01 from the MDVRP instances used in Cordeau et al. (1997) which includes 50 customers and 4 depots, i.e., companies in our case.

In total, 10 scenarios are investigated, divided into four categories. The detailed parameter settings is given in Table 5.4:

- Size of coalition group includes scenarios SC1 and SC2 in which the maximum size of the coalition is limited to 3 and 2, respectively.
- Degree of integration disabling Type III Cooperation (SC3) or Type II Cooperation (SC4), respectively.
- Synergy requirement group investigates the effect of negotiation process rules by giving more power to the bidder (SC5) or to the auctioneer (SC6), or setting those synergy requirements at 0% (SC7).
- Trust indicator adjustment with SC8 representing the full trust environment, in which companies will always cooperate as early and much as possible, SC9 improving the trust rewarded by achieving savings, and SC10 increasing the initial trust indicator and the trust rewarded.

Table 5.4. Parameter setting

	Scenario	$\sigma$	$\tau$	$\delta$	$\epsilon$	MaxSize	Type I	Type II	Type III
Size of coalition	Base	0.2	0.2	0	0	4	X	X	X
	SC1	0.2	0.2	0	0	3	X	X	X
	SC2	0.2	0.2	0	0	2	X	X	X
Degree of integration	SC3	0.2	0.2	0	0	4	X	X	
	SC4	0.2	0.2	0	0	4	X		
Synergy requirement	SC5	0.1	0.3	0	0	4	X	X	X
	SC6	0.3	0.1	0	0	4	X	X	X
	SC7	0	0	0	0	4	X	X	X
Trust indicator	SC8	0.2	0.2	1	1	4	X	X	X
	SC9	0.2	0.2	0	0	4	X	X	X
	SC10	0.2	0.2	0.15	0.15	4	X	X	X

General results for the base scenario are given in the Figure 5.4 (distance-based costs) and Figure 5.5 (emissions). On the horizontal axis, the different types of cooperation and sizes are presented in the following way: the first two letter refer to the level of integration (Type I-T1-, Type II -T2, and Type III -T3-), while the following two state the number of companies in the coalition (2C: two companies). Moreover, the code 'N' and 'NC' at the end indicate whether the members of the coalition acts with cooperation or without, respectively. Finally, data showed in both figures corresponds to average costs/CO<sub>2</sub> obtained under each setting of integration and size for 100 replication runs of the simulation.

Figure 5.4. Boxplot for distance-based costs in the base scenario by type and size of coalition.

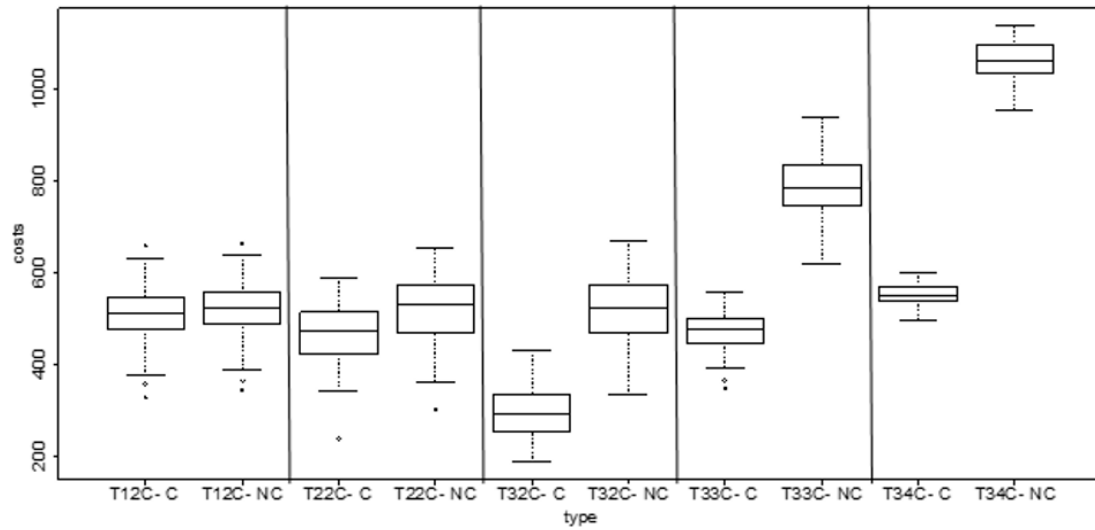
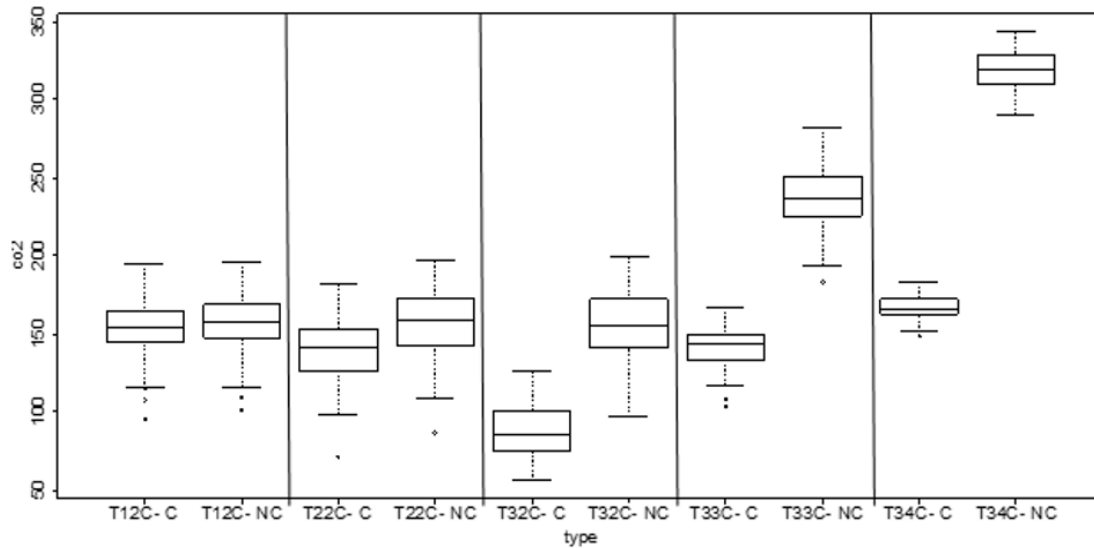


Figure 5.5. Boxplot for CO<sub>2</sub> (Kg) emissions in the base scenario by type and size of coalition.



The Table 5.5 shows the differences (gaps) in economic and environmental aspects, computed by the improvement of the cooperative scenario over the non-cooperative one. Average time spent in any setting of integration and size is also available in the 'time' column, given in weeks. The last column represent the average gap in the aggregated configuration, that is, once a coalition is successfully set up, the model saves the costs/CO<sub>2</sub> that the members of the coalition would get in case they were not in the coalition. The aggregation of that data within the whole time frame is given in the 'aggregation' column as the gap between the no cooperation and cooperation setting. For those settings in which no time is spent, no improvements are reported (x). Additionally, the impact of integration degree and size combinations is provided in Table 5.6. Complete data including the absolute values of each individual test runs are available at <http://short.boku.ac.at/instances>.



Results show significant savings can be achieved by cooperation. In the base scenario, a Type I Cooperation lasts about 23 weeks (almost half of the time frame) achieving savings of around 1.8% in both economic and environmental figures. Later, the coalition upgrades to a Type II Cooperation and achieves savings of around 10% in distances and CO<sub>2</sub> emissions for an average time period of three weeks. Finally, the coalition stays 29 weeks under a Type III agreement (five with two members, four with three members, and 19 in the grand coalition, i.e., 36% of the time companies act as a grand coalition). Savings in the different sizes of the Type III Cooperation account for 40 %, 43% and 49 %, respectively for economic and environmental aspects. In total, the cooperation within the 52 weeks results in an average of 18% of economic and environmental savings.

Table 5.5. Results for SC1-SC10

		S	Type I Cooperation			Type II Cooperation			Type III Cooperation			Aggregated	
			Time (w)	Costs gap	CO <sub>2</sub> gap	Time (w)	Costs gap	CO <sub>2</sub> gap	Time (w)	Costs gap	CO <sub>2</sub> gap	Costs gap	CO <sub>2</sub> gap
Base Scenario		2	22.94	-1.97%	-1.74%	3.875	-9.29%	-10.30%	5.44	-39.80%	-39.95%		
		3	-	-	-	0	x	x	4.33	-43.33%	-43.94%		
		4	-	-	-	0	x	x	18.93	-48.04%	-47.79%		
Size of Coalition	SC1	2	27.1	-2.00%	-1.65%	4.16	-9.18%	-10.97%	4.32	-39.48%	-39.38%		
		3	-	-	-	0	x	x	22.18	-43.25%	-43.48%		
		4	-	-	-	-	-	-	-	-	-		
	SC2	2	23.22	-2.00%	-1.76%	3.89	-8.92%	-10.04%	26.9	-41.63%	-42.06%		
		3	-	-	-	-	-	-	-	-	-		
		4	-	-	-	-	-	-	-	-	-		
Degree of Integration	SC3	2	26.5	-1.86%	-1.74%	9.11	-9.61%	-10.46%	-	-	-		
		3	-	-	-	9.40	-15.7%	-15.71%	-	-	-		
		4	-	-	-	18.08	-17.80%	-17.82%	-	-	-		
	SC4	2	49.65	-1.97%	-1.73%	-	-	-	-	-	-		
		3	-	-	-	-	-	-	-	-	-		
		4	-	-	-	-	-	-	-	-	-		
Synergy Requirement	SC5	2	22.67	-2.38%	-2.08%	3.61	-9.13%	-10.10%	5.20	-40.04%	-39.93%		
		3	-	-	-	0	x	x	4.39	-43.24%	-43.50%		
		4	-	-	-	0	x	x	21.03	-47.871%	-47.71%		
	SC6	2	23.60	-2.42%	-2.09%	3.86	-9.13%	-10.10%	4.75	-39.50%	-39.88%		
		3	-	-	-	0	x	x	4.55	-41.86%	-42.26%		
		4	-	-	-	0	x	x	20.21	-47.95%	-47.77%		
	SC7	2	23.36	-2.03%	-1.89%	4.44	-9.13%	-9.80%	4.97	-39.45%	-39.45%		
		3	-	-	-	0	x	x	4.75	-41.38%	-41.59%		
		4	-	-	-	0	x	x	20.21	-47.24%	-47.12%		
Trust Indicator	SC8	2	1	-3.55%	-2.92%	1	-8.43%	-11.99%	4.10	-39.80%	-39.79%		
		3	-	-	-	0	x	x	2.69	-41.66%	-42.16%		
		4	-	-	-	0	x	x	42.36	-47.72%	-47.53%		
	SC9	2	14.61	-2.06%	-1.71%	2.02	-8.79%	-11.13%	3.05	-39.79%	-39.42%		
		3	-	-	-	0	x	x	4.49	-41.75%	-42.16%		
		4	-	-	-	0	x	x	26.58	-47.79%	-47.60%		
	SC10	2	7.9	-2.09%	-1.91%	1.78	-8.76%	-11.3%	3.60	-39.79%	-40.05%		
		3	-	-	-	0	x	x	2.92	-42.42%	-42.61%		
		4	-	-	-	0	x	x	34.86	-47.50%	-47.39%		

When the size of coalition is limited to two or three members, aggregated savings are substantially reduced. Nevertheless, savings are much more reduced when the degree of integration is limited instead of the size of the coalition. Aggregated savings reaches about 5% when Type III is not allowed and only 1% when neither Type II nor Type III are allowed. With respect to the synergy requirement effects, results are quite similar to the ones obtained in the base scenario. However, savings in SC5 are significantly larger because, on average, the coalition gets faster to a Type III agreement. Note that in SC5, it is the bidder who has more power in the negotiation process. SC7, the setting with synergy requirements set to 0 %, results in a weaker performance. This is because savings obtained at the beginning of the coalition are so low that this reduces the motivation for the members of the coalition to improve their relationship. Once trust rules are relaxed, effects on savings grow enormously. If the companies trust each other fully (SC8), the grand coalition is reached extremely fast, doubling the potential savings with respect to the base scenario. Biasing positively the way in which trust is rewarded also improve savings to 28 %, mainly by reducing the time spent in Type I and II cooperation.

#### **4. Conclusions**

This chapter develops an agent-based simulation model to investigate the effect of HC from economic and environmental perspectives. In contrast to recent literature in L&T, this article considers trust-related issues when running a coalition and focuses on the evolution of the coalition over time within a dynamic perspective. Therefore, cooperation, leadership, negotiation processes, savings allocation, and coalition forming as well as the evolution of a coalition in both members and degree of integration are considered within in the simulation framework.

Results show that significant savings can be achieved by cooperation. In our simulation model, HC effects grow exponentially with the number of companies involved in the agreements once a high degree of integration is achieved. Moreover, the degree of integration plays a crucial role in the savings achieved, being much more important than the numbers of companies involved. Synergy requirement does not show to be quite determinant, however, a value larger than 0 for these parameters is preferable as it potentially allows larger savings early in the coalition. This eventually accelerates the degree of integration and increases total savings. In contrast, trust-related issues have been revealed as a huge barrier to achieve larger savings in economic and environmental aspects. In a full trusted environment, achieved savings are doubled compared to the savings obtained in the base scenario.

Future work focuses on the introduction of dynamic events such as sudden market entries and exits to the simulation frameworks. This allows one to study how the coalition reacts to disruptions and, consequently, enables the investigation of the robustness of a coalition.

Furthermore, the consideration of competing coalitions within the same time frame in a wider geographical scope is of interest.

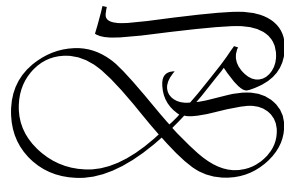
Table 5.6. Integration-Size combinations. Aggregated results.

		Up to...					
		T1		T2		T3	
	$ \mathcal{S} $	Costs	CO <sub>2</sub>	Costs	CO <sub>2</sub>	Costs	CO <sub>2</sub>
Up to...	2	-0.94%	-0.83%	-2.67%	-2.70%	-9.68%	-9.76%
	3	-	-	-4.75%	-4.74%	-10.37%	-10.68%
	4	-	-	-5.35%	-5.35%	-18.86%	-18.82%



## CHAPTER 6.

# LOCATING A BIOREFINERY IN NORTHERN SPAIN: DECISION MAKING AND ECONOMIC CONSEQUENCES



iofuels are emerging as a prominent renewable and sustainable energy sources in developed countries. In this sense, this paper presents a case study in which a biorefinery has to be sited is investigated in Northern Spain. Thus, the strategic decision of locating such a facility is deeply investigated through strategic policy evaluation. Then, tactical decisions ranging from purchase policy, transport policy and storage policy are carried out. Only local and limited biomass can be harvested for supplying the biorefinery through a heterogeneous vehicle fleet and two different and mutually exclusive storage strategies are evaluated: direct supply from crops to biorefinery and using intermediate collectors. Additionally, crop exploitation factors and biorefinery sizes are used to generate several scenarios in which the strategic decision of location as well as all the tactic decisions are made. Some mixed integer linear programming models are proposed to figure out all relevant decision problems. The results suggest that the northwest study area as the best option to locate the biorefinery and recommend the intermediate-collector storage strategy. Moreover, key information about critical biomass, crops and times are also provided.

This chapter is based in the following research contributions:

Serrano-Hernandez, Faulin, J. Locating a Biorefinery in Northern Spain: Decision Making and Economic Consequences. *Socio Economic Planning Sciences*, under review.

Serrano-Hernandez, A., Faulin, J., Pintor, J. M., & Belloso, J. (2017). Determining an Optimal Area to Locate a Biorefinery under Economic and Environmental Criteria. *Transportation Research Procedia*, 22, 95-104.

Serrano, A., Faulin, J., Astiz, P., Sánchez, M., and Belloso, J. (2015). Locating and designing a biorefinery supply chain under uncertainty in Navarre: a stochastic facility location problem case. *Transportation Research Procedia*, 10, 704-713.

## 1. Introduction

The consequences of choosing a wrong place to locate a facility may be dire. Appropriate location of industrial plants is particularly important to contribute to economic, social and sustainable objectives, so it should not be superficially done. Therefore, it is required to analyze all alternatives and investigate conditions surrounding them in terms of infrastructure and supply.

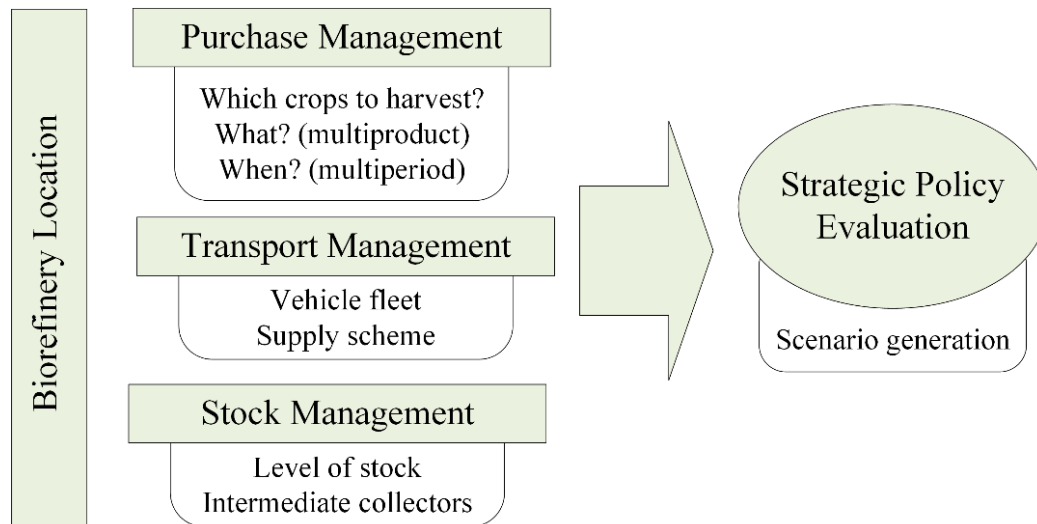
In that sense, facility location decisions have a strategic nature. Generally, they are made for the long run and involve the whole company. Then, operational and tactics decisions are made based on the strategic infrastructure previously designed. Papadakis and Barwise (2012) developed five characteristics of strategic decisions: (1), they are huge, risky and with long term effects; (2), they are a link between thoughtful and emergent strategy; (3), they are a source of company knowledge; (4), they are a critical and challenging step for individual managers; and (5), they are highly multidisciplinary. Thus, a high degree of reflection and judgment by the decision maker is required to deal with such decisions.

Biofuels are considered a promising alternative to conventional fossil fuel in the short and medium term. The European Union is heavily dependent on imported energy resources, especially oil. Actually, 65% of oil consumption in EU is burnt in the transport sector, which contributes to increase greenhouse gas emissions (European Environment Agency, 2015). According to the same institution, if measures are not taken, the dependence of the EU on imported oil could rise to 90% by 2020 and Europe will be unable to achieve the goal of reducing emissions of greenhouse gases by 20% by 2020. In this context, finding alternative sources of energy for transport is essential to divert oil demand towards less polluting sources. Therefore, encouragement of the use of biofuels in transport (mainly bioethanol and biodiesel) has become a priority in the EU energy policies. Moreover, bioproducts market is constantly expanding as applications in pharmaceutical, chemical, paper, and energy sectors are increasing. The link between biomass and bioproduct is the biorefinery. A biorefinery is the integrated facility in which it is used biomass for the production of bioproducts through thermochemical (combustion, gasification, pyrolysis and/or liquefaction) and biological (fermentation, anaerobic digestion, and/or biologic transesterification) processes. Additional general and technical information about biomass, biorefineries and bioproducts can be found in Aresta et al. (2012).

The Strategic Policy Evaluation aims to determine the effects of strategic decisions on business performance through evaluating several scenarios. In this work, it will be presented a case study in which a biorefinery has to be located in Northern Spain given the available biomass in the area. Based on the strategic decision of location, supply chain is adjusted and tactics decisions of purchase policy, transport policy and storage policy are made. Purchase policy involves the kind of biomass to be bought and the crops they come from. Due to feedstock seasonality, a time factor is included. Transport policy comprises quantities to be transported and the type of vehicle used.

Finally, storage policy defines optimal level of stocks. The strategy policy evaluation overview is given in Figure 6.1. Moreover, two different storage strategies are evaluated: whether having intermediate-collectors or not. For organizational purposes, next section review the related literature to biorefineries and location modelling. Section 3 introduces the detailed problem, defines the geographical space, and shows the experimental data. Later, results are presented and discussed. Finally, section 5 gives some concluding remarks.

Figure 6.1. Strategic Policy Evaluation overview



## 2. Related literature

Preliminary works of this chapter can be found in [Serrano-Hernandez et al. \(2015\)](#) and [Serrano-Hernandez et al. \(2017\)](#). In the former, stochasticity of biomass is investigated to determine the biorefinery size. Afterward, the biorefinery is placed accordingly. In the later, a deeper analysis was run: economic and environmental criteria were taken into account to site a biorefinery in Navarre (Spain). Then, purchase management, transport policy and storage planning was optimized. Main differences between those papers and this one are related to the study area, biomass information, model definition and complexity, and conclusions.

Facility location problems are widely studied in the literature. Due to its strategic nature, facility location works are extremely linked to business decisions science. Therefore, those facilities that may be considered significant because their large investment (hotels, huge industrial plants...) or special circumstances (residual wastes, hospitals...) have received attention from the scientific community. Additionally, facility location is highly important for companies that look beyond their country borders and seek for a new place to establish them as observed by [Spigarelli and Ly \(2016\)](#). To do so, they defined the determinants for Chinese companies to expand in Europe, finding that countries with minor rule of law and higher Gross Domestic Product (GDP)

per capital are more attractive. In the tourism sector, according to [Lado-Sestayo et al. \(2016\)](#), hotel location is, mainly, the only success factor. They also remarked that credit institutions usually focus on location factors when they have to decide to support a hotel project. Similar conclusions were found by [Yang et al. \(2014\)](#) and [Masiero et al. \(2015\)](#). Industrial plant location is further investigated by [Ayodele et al. \(2016\)](#) looking for wind turbine best locations in which they had to care about the wind power in Africa. General information about facility location problems, its role inside the supply chain and sustainability can be found in [Zanjirani, and Hekmatfar \(2009\)](#); [Chen et al. \(2014\)](#) and [Melo et al. \(2009\)](#).

Some works related to biorefinery location can be found in the recent literature. Mainly, those works implement geographical information systems (GIS) in traditional optimization (cost minimization, net present value (NPV) maximization problems), multiobjective optimization, and strategies based on marginal prices. Traditional optimization is investigated by [Xie et al. \(2009\)](#). They aim to develop a tool to support decision making based on GIS to determine the best location of biorefineries. Candidate locations consisted of several points defined beforehand. Then, a mixed integer linear programming (MILP) model is run to minimize transportation cost. Similarly, [Marvin et al. \(2013\)](#) claim that due to important logistic decisions arise (i.e., the location), binary variables should be included. This approach results in MILP models. In this case, the model solves the location and size of several biorefineries as well as their technology and network. Then, the net present value (NPV) chain is optimized within the whole biomass supply chain. Further biomass supply chain characteristics were also investigated in [San Miguel et al. \(2015\)](#). Finally, NPV is again used by [Yu et al. \(2014\)](#).

Interesting research based on multi criteria optimization can be discovered in [Mele et al. \(2009\)](#), [You and Wang \(2011\)](#) and [You et al. \(2012\)](#). [Mele et al. \(2009\)](#) developed a bi-objective MILP in which costs of producing sugar cane as well as its environmental impact are taken into account in an Argentinian region to place energy facilities. A similar study was carried out in Italy ([Delivand et al., 2015](#)). Economic (costs) and environmental (greenhouse gas (GHG) emissions) balance is also explored in [You and Wang \(2011\)](#). They developed a multi-period MILP with 49 restrictions to collect the characteristics of the “biomass to liquid” supply chain. Decision variables had to do with the number, size, location and technology of each biorefinery. Thirdly, in the [You et al. \(2012\)](#) work, a three objective problem is presented: environmental (GHG emissions), economic (total annual cost) and social (job creation) criteria. The model simultaneously solves the optimal location and technology of two biorefineries, network design, inventory control, capital investment and other decision variables related to operation management. Epsilon constraint methodology was followed to generate Pareto curves within the three goals.



The change in cost to deliver feedstock as the quantity of required feedstock increases is known as marginal costs (Haque et al. 2014). This concept is widely used to determine the best location for new energy facilities like biorefineries as shown by Panichelli et al (2008). Their proposed methodology can be divided into four steps:

- Firstly, create a map of farmland availabilities. The map is divided in 1km x 1km pixels with four pieces of information each: county to which it belongs, the type of soil it has, the proportion of appropriateness for energy crops and the percentage of the county that is suitable for conversion to energy crop.
- Secondly, calculation of the price. The price of a ton of raw material produced will be equivalent to what the farmer would get with their current settings crops during the life of the biorefinery (a NPV is used to this purpose).
- Thirdly, mapping the cost of a unit of raw material. Using the information of steps 1 and 2, it results in a map with potential biomass supply at each pixel with its price. Then, transport costs are calculated from one pixel to another.
- Fourthly, location of facilities. Potential locations are selected sequentially based on the lower cost previously obtained.

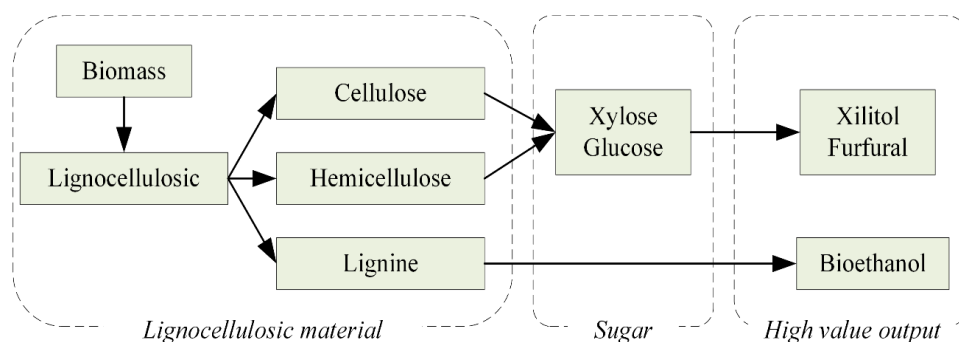
### 3. Problem definition

#### 3.1. The biorefinery

A lignocellulosic biorefinery is planned to be placed in northern Spain, covering the regions of Navarre, Aragon and La Rioja. They are leading regions in Spain in renewable energy generation, mainly wind and solar, and they are continuously investing on research and development in order to diversify their energy production. In this sense, bioenergy is seen as a good option to reinforce their leading position. Lignocellulosic biorefineries may use wood, agricultural residues, and energetic crops as biomass. However, due to project characteristics and resource availabilities, just agricultural residues coming from the study region can be used. In a lignocellulosic biorefinery, pentose and hexose saccharides (sugar derived from the biomass) are separated to produce bioethanol and higher value chemicals commodities. Broadly speaking, biorefinery faces a four-hold process, as shown in Figure 6.2: (i) extracting lignocellulosic material from biomass; (ii) decomposing lignocellulosic into cellulose, hemicellulose and lignine; (iii) hydrolysis of cellulose and hemicellulose to obtain glucose and xylose; (iv) fermentation of glucose and xylose to obtain bioethanol and high value chemical commodities (xylitol and furfural). The reader can find a complete report on lignocellulosic biorefineries in Luo et al. (2010).

Finally, biorefinery size, measured in terms of biomass consumption, is not explicitly optimized, as several size-related scenarios will be considered instead.

Figure 6.2. Simplified lignocellulosic biorefinery process, based on Luo et al. (2010)



### 3.2. The biomass

Projects based on seasonal natural resources such as biomass are highly geographically dependent. With this respect, availability and density of biomass is investigated focusing on agricultural residues. Note that due to project characteristics only local biomass can be used, i.e. imports are not allowed. Consequently, cereal straw, rice straw, corn straw, rape straw and alfalfa are selected as feedstock to the biorefinery because their wide implementation in the study area (Department of Agriculture of Navarre, 2016; Department of Agriculture of Aragon, 2016; Department of Agriculture of La Rioja, 2016). Winter cereal straws (which include wheat, oat and barley) are the predominant source of biomass in the three regions. They account for about 700,000 annual tons during the previous 15 years. The high seasonality is the main drawback being only available to be harvested during June, July and August. On the other hand, a low humidity rate (around 12%) and reduced price (around 55-65 €/ton) make cereal a good option. Alfalfa production is about 300,000 tons per year and is available from March to October, but it has higher humidity rate (60%) and price (80-100 €/ton). Corn straw is the third most popular biomass in the region with 200,000 tons. It is available in winter time (from November to January), and it has around 25% humidity with a cost of 65-75 €/ton. Finally, rape and rice straws are also taken into account, even though they represent a small share in the total production. Biomass summary is showed in Table 6.1.

Table 6.1. Biomass summary available in the study region

Biomass	Availability (months)	Quantity ('000 tons)	Humidity (%)	Price (€/ton)
Winter Cereal Straw	June-August	2,000	12	55-65
Corn Straw	Nov- January	1,250	25	50-70
Alfalfa	March- October	1,000	60	80-110
Rape Straw	July- August	50	12	70-90
Rice Straw	October-Nov	50	27	55-75

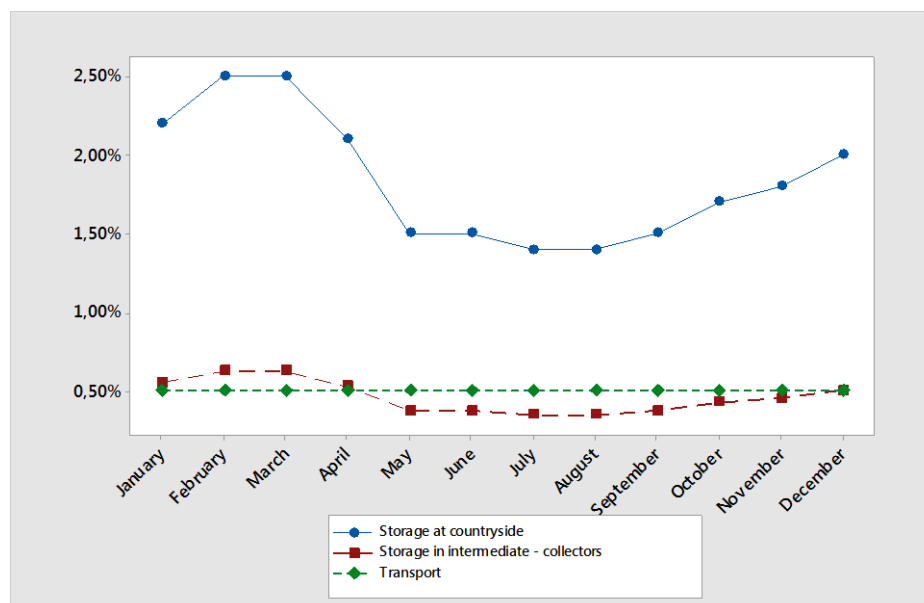
In order to guarantee sustainability (soil, prices, animal feeding...) an exploitation factor is used in every crop and for each biomass product. It means the proportion of the total resources availability that effectively could be used for supplying a biorefinery. Those exploitation factors were carefully chosen conjointly with the Navarrese Agricultural Department based on soil characteristics and current agricultural practice. However, in order to generate several scenarios, the exploitation factor will be thoughtfully analyzed in both cases: an increase and decrease of 50%.

### *3.3. The storage*

Two strategies can be assessed in storage policy. On the one hand, biomass can be unlimitedly stored at the supply point, outside in the countryside. On the other hand, biomass can be transported to a limited-capacity intermediate-collector from crops fields. According to the project characteristics both strategies are mutually exclusive. That is, decision maker has to choose between the direct supply and the possibility of having intermediate collectors. Intermediate-collectors used in this work are rustic warehouses placed in the countryside. They have a 15,000 tons capacity in a 2,400 square meters surface. Real market prices, based on company interviews, were used. Consequently, a yearly fix rent which includes insurance and basic upkeep is taken into account. Additionally, a variable handling cost at the intermediate collector is employed.

Direct supply strategy provides a higher flexibility with respect to the vehicles to choose. It means that transportation from crops to the biorefinery can be made with any type of vehicle. Alternatively, intermediate-collector strategy uses a fix assignment of vehicle as they are usually placed in the countryside with a very limited accessibility. With this respect, only small vehicles can reach to intermediate-collectors from crops because they usually are linked by rural roads. If the vehicle is going directly to the potential biorefinery point from the crop, a large vehicle can be used because of the good communications. Finally, only medium size vehicles can departure from the intermediate-collector facilities. Next subsection will describe vehicle characteristics. Difference in biomass depreciation is the critical factor between both strategies. Intermediate-collectors offer a great protection against external agents: wind, rain, humidity and even thieves. Therefore, depreciation rates are significantly lower in the intermediate collectors than in the countryside. Figure 6.3 shows time dependent depreciation rates, noting that in winter and springtime they are significantly higher due to climate conditions. Figure 6.3 also shows the depreciation as a result of the transport activity. This information was elaborated based on internal studies carried out by Spanish Agricultural agencies.

Figure 6.3. Depreciation rates in countryside, intermediate-collectors and transport in Spain



### 3.4. The vehicles

Three types of vehicles are proposed to transport biomass from crops to intermediate-collectors and/or to the biorefinery. Large vehicle (L) is characterized for its higher capacity, being able to transport up to 32 tons. Its huge dimensions make it unappropriated to drive in small roads such as regional or rural ones. Medium vehicle (M) is a traditional truck capable to carry up to 15 tons. Since it is smaller, it is allowed to drive in regional roads but not in rural ones. Finally, small vehicle (S) is a compact and manageable truck, suitable for rural roads. Vehicles characteristics are shown in Table 6.2.

Table 6.2. Vehicles Characteristics

	Vehicle L	Vehicle M	Vehicle S
Capacity (tons)	32	15	9
Horsepower	600	500	160
Axis	6	5	2
Allowed in*	HW, NR	HW,NR, ReR	HW, NR, ReR, RuR

\* HW: Highway; NR: National road; ReR: Regional road; RuR: rural road

When the problem faces the direct supply strategy, vehicles are freely selected in the model because crops and potential biorefineries are connected by highways and national roads. However, vehicle characteristics will determine somehow intermediate-collector alternative. Real prices were taken into account based on official estimations (Spanish Ministry of Transportation, 2016). Therefore, truck fixed costs and distance dependent cost were carefully added to the model noting that the larger is the vehicle. Thus, the higher fixed costs are, the lower the variable costs are.

### 3.5. The decisions

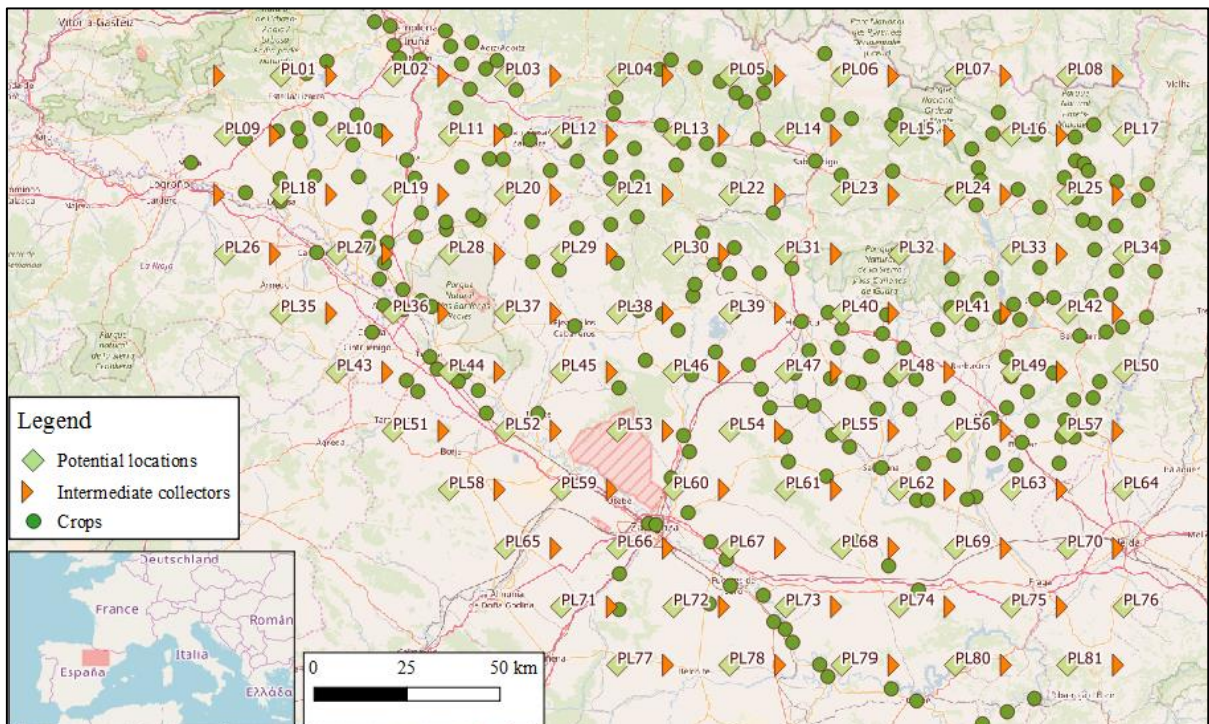
A lignocellulosic biorefinery is investigated to be set up in Northern Spain, covering the regions of Navarre, La Rioja and Aragon. The total area accounts for more than 42,000 square kilometers, around 8% of Spain. Only local and limited biomass (winter cereal straw, corn straw, alfalfa, rape straw, and rice straw) can be harvested for supplying the biorefinery. Two different and mutually exclusive storage strategies have to be assessed:

- (1) Direct supply from crops fields to biorefinery. Biomass is, mainly, stored in the countryside with higher depreciation rates. Any kinds of vehicles (L, M, and S) can be used to transport the biomass.
- (2) Intermediate-collectors alternative provide a lower depreciation rates. However, an investment on warehouse facilities must be made and lower truck flexibility is considered.

Additionally, exploitation factors (the proportion of the total biomass available that effectively could be used for supplying a biorefinery) and biorefinery size (measured as biomass consumption) will generate several scenarios in which the strategic decision of location and all the tactic decisions (purchase policy, transport policy and storage policy) must be taken giving us a reliable strategy policy evaluation.

Figure 6.4 shows the geographical scope of the problem considered. Firstly, potential locations to host a biorefinery are represented by diamonds. Secondly, triangles stand for potential places to set up intermediate-collectors. Finally, green circles denoted the crops location.

Figure 6.4. Potential locations (diamonds), intermediate collectors (triangles) and crops fields (circles) located in the decision-making regions in Northern Spain

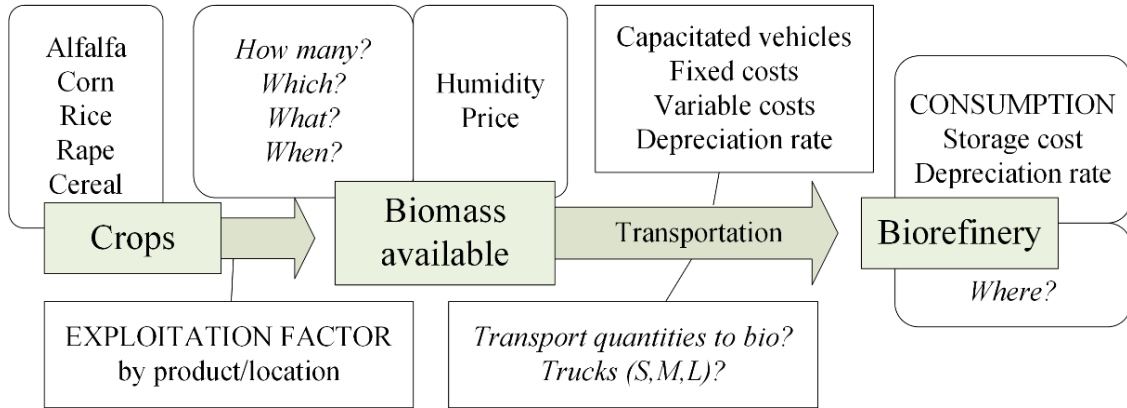




#### 4. The direct Supply Model (DSM)

DSM is summarized in the Figure 6.5. Note that questions in *italic* correspond to decision variables and capital letters are the key parameters for scenario generation. The detailed program formulation of the DSM in GAMS® code is available in the [Appendix 1](#) of this thesis.

Figure 6.5. Direct supply model overview



DSM is formulated as mixed integer programming model in which sets, decision variables and parameters are described in Table 6.3, Table 6.4, and Table 6.5, respectively.

Table 6.3. Direct supply model sets description

Set	Description	Range
$I$	Set of crops fields	$i = 1,2 \dots 354$
$J$	Set of potential biorefineries	$j = 1,2 \dots 81$
$K$	Set of vehicles	$k = S, M, L$
$P$	Set of products	$p = 1,2 \dots 5$
$T$	Set of months	$t = 1,2 \dots 12$

Table 6.4. Direct supply model decision variables description

Variable	Description
$X_j$	1 if the biorefinery is built in potential location $j$ , 0 otherwise
$V_{ijkt}$	number of trucks going from crop $i$ to biorefinery $j$ of type $k$ at time $t$
$B_{ijkpt}$	tons of product $p$ bought in crop $i$ at time $t$ to serve potential location $j$
$C_{pit}$	biorefinery $j$ consumption of product $p$ at time $t$
$BS_{jpt}$	Stock corresponding to potential location $j$ of product $p$ at time $t$ in

Table 6.5. Direct supply model parameter description

Parameter	Description	Unit
$h_p$	humidity of product $p$	%
$\eta$	biorefinery monthly consumption	Tn
$\xi_{pt}$	1 if product $p$ is available at $t$	-
$d_{ij}$	distance from crop $i$ to potential location $j$	Km
$cap_k$	capacity of vehicle $k$	Tons
$\phi_p$	season duration of product $p$	Months
$\varphi_p$	price of product $p$	€
$\psi_{ip}$	total production of $p$ in $i$	Tn
$\alpha_{pi}$	exploitation factor of product $p$ in $i$	%
$FC_k$	transportation fix cost of vehicle $k$	€
$VC_k$	transportation variable cost of vehicle $k$	€/km
$\varsigma$	stock cost	€/Tn/month
$\delta_t$	losses on stock from time $t$ to time $t+1$	%
$\gamma$	losses on transportation	%

The DSM is as follows:

$$\min totalCosts = biomassCosts + transportCosts + storageCosts \quad (6.1)$$

$$biomassCosts = \sum_i \sum_j \sum_k \sum_p \sum_t B_{ijkpt} \varphi_p \quad (6.1.1)$$

$$transportCosts = \sum_i \sum_j \sum_k \sum_t FC_k V_{ijkt} + 2 VC_k V_{ijkt} d_{ij} \quad (6.1.2)$$

$$storageCosts = \sum_j \sum_p \sum_t BS_{jpt} \varsigma \quad (6.1.3)$$

Subject to:

$$\sum_j X_j = 1 \quad (6.2)$$

$$\sum_i \sum_k B_{ijkpt} (1 - \gamma) + S_{jpt-1} (1 - \delta_t) = \frac{C_{pjt}}{1 - h_p} + BS_{jpt}; \forall i \in I, \forall j \in J, \forall p \in P, \forall t \in T \quad (6.3)$$

$$\sum_k B_{ijkpt} \leq \psi_{ip} \alpha_{pi} \frac{\xi_{pt}}{\phi_p}; \forall i \in I, \forall j \in J, \forall p \in P, \forall t \in T \quad (6.4)$$

$$\sum_p C_{jpt} = X_j \eta; \forall j \in J, \forall t \in T \quad (6.5)$$

$$V_{ijkt} \geq \sum_p \frac{B_{ijkpt}}{cap_k}; \forall i \in I, \forall j \in J, \forall p \in P, \forall t \in T \quad (6.6)$$

In which the objective function (6.1) minimizes the total supply chain costs and it is divided into the three considered sources of costs: the costs of purchasing the biomass (6.1.1), the costs of transporting the biomass (6.1.2) and the costs of stocking the biomass (6.1.3).

Constraint (6.6) determines that one biorefinery must be sited. Constraints (6.3) describe the intertemporal flows of biomass taking into consideration humidity and depreciation. Constraints (6.4) state resources availabilities with productions and exploitation factors. Constraints (6.5) fix the monthly size (consumption) of the biorefinery. Finally, constraints (6.6) define maximum vehicle capacities.

## 5. The Intermediate Collector Model (ICM)

ICM is described in the Figure 6.6. As in the previous model, questions in italic correspond to decision variables and capital letters are the key parameters for scenario generation. The detailed program formulation of the ICM in GAMS® code is available in the [Append 2](#) of this thesis.

The ICM is also formulated as mixed integer programming model in which sets, decision variables, and parameters are described in Table 6.6, Table 6.7 and Table 6.8, respectively.

Figure 6.6. Intermediate-collectors model overview

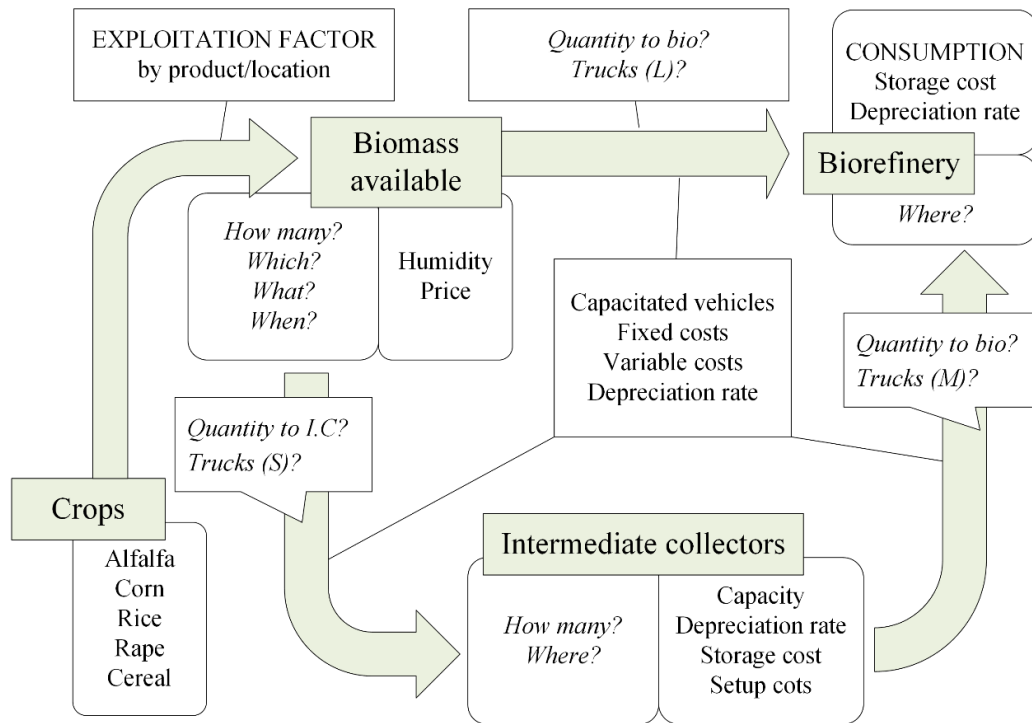


Table 6.6. Set description

Set	Description	Range
$I$	Set of crops fields	$i = 1,2 \dots 354$
$J$	Set of potential biorefineries	$j = 1,2 \dots 81$
$W$	Set of intermediate-collector	$w = 1,2 \dots 79$
$P$	Set of products	$p = 1,2 \dots 5$
$T$	Set of months	$t = 1,2 \dots 12$



Table 6.7. Decision variables description

Variable	Description
$X_j$	1 if the biorefinery is built in potential location $j$ , 0 otherwise
$Y_w$	1 if the an intermediate-collector $w$ is set up, 0 otherwise
$Q_{ijpt}^{crop \rightarrow bio}$	Tons of product $p$ bought in crop $i$ transported to biorefinery $j$ at time $t$
$Q_{iwpt}^{crop \rightarrow IC}$	Tons of product $p$ bought in crop $i$ transported to $w$ at time $t$
$Q_{wjpt}^{IC \rightarrow bio}$	Tons of product $p$ in $w$ transported to biorefinery $j$ at time $t$
$V_{ijkt}^L$	Number of large trucks going from crop $i$ to biorefinery $j$ at time $t$
$V_{iwkt}^S$	Number of small trucks going from crop $i$ to $w$ at time $t$
$V_{wjkt}^M$	Number of medium trucks going from $w$ to biorefinery $j$ at time $t$
$B_{ipt}$	Tons of product $p$ bought in crop $i$ at time $t$
$C_{pit}$	Biorefinery $j$ consumption of product $p$ at time $t$
$BS_{jpt}$	Stock corresponding to potential location $j$ of product $p$ at time $t$ in
$CS_{wpt}$	Stock corresponding to intermediate-collector $w$ of product $p$ at time $t$

Table 6.8. Parameter description

Parameter	Description	Unit
$h_p$	humidity of product $p$	%
$\eta$	biorefinery monthly consumption	Tn
$\beta$	proportion of consumption which can be stock at the bio	%
$\xi_{pt}$	1 if product $p$ is available at $t$	-
$d_{ij}$	distance from crop $i$ to potential location $j$	Km
$d_{iw}$	distance from crop $i$ to intermediate-collector $w$	Km
$d_{wj}$	distance from $w$ to potential location $j$	Km
$cap^L$	capacity of a large vehicle	Tons
$cap^S$	capacity of a small vehicle	Tons
$cap^M$	capacity of a medium vehicle	Tons
$\phi_p$	season duration of product $p$	Months
$\varphi_p$	price of product $p$	€
$\psi_{ip}$	total production of $p$ in $i$	Tn
$\alpha_{pi}$	exploitation factor of product $p$ in $i$	%
$FC^L$	transportation fix cost of a large vehicle	€
$FC^S$	transportation fix cost of a small vehicle	€
$FC^M$	transportation fix cost of a medium vehicle	€
$VC^L$	transportation variable cost of a large vehicle	€/km
$VC^S$	transportation variable cost of a small vehicle	€/km
$VC^M$	transportation variable cost of a medium vehicle	€/km
$\varsigma$	stock cost at biorefinery	€/Tn/month
$\omega$	cost of setting up an intermediate-collectors	€
$\rho$	capacity of intermediate-collectors	Tn
$\kappa$	stock cost at intermediate-collector	€/Tn/month
$\delta_t$	losses on stock from time $t$ to time $t+1$	%
$\gamma$	losses on transportation	%

The ICM is as follows:

$$\min totalCosts = biomassCosts + transportCosts + storageCosts \quad (6.7)$$

$$biomassCosts = \sum_i \sum_j \sum_k \sum_p \sum_t B_{ijkpt} \varphi_p \quad (6.7.1)$$

$$transportCosts = \left\{ \begin{array}{l} \sum_i \sum_j \sum_t CF^L V_{ijt}^L + 2 CV^L V_{ijt}^L d_{ij} + \\ + \sum_i \sum_w \sum_t CF^S V_{iwt}^S + 2 CV^S V_{iwt}^S d_{iw} + \\ + \sum_w \sum_j \sum_t CF^M V_{wjt}^M + 2 CV^M V_{wjt}^M d_{wj} \end{array} \right. \quad (6.7.2)$$

$$+ \sum_i \sum_w \sum_t CF^S V_{iwt}^S + 2 CV^S V_{iwt}^S d_{iw} + \quad (6.7.3)$$

$$+ \sum_w \sum_j \sum_t CF^M V_{wjt}^M + 2 CV^M V_{wjt}^M d_{wj} \quad (6.7.4)$$

$$storageCosts = \left\{ \begin{array}{l} \sum_j \sum_p \sum_t BS_{jpt} S + \\ + \sum_w \sum_p \sum_t CS_{wpt} \kappa + \sum_w Y_w \omega \end{array} \right. \quad (6.7.5)$$

$$+ \sum_w \sum_p \sum_t CS_{wpt} \kappa + \sum_w Y_w \omega \quad (6.7.6)$$

Subject to:

$$\sum_j X_j = 1 \quad (6.8)$$

$$B_{ipt} \leq \psi_{ip} \alpha_{pi} \frac{\xi_{pt}}{\phi_p}; \quad \forall i \in I, \forall p \in P, \forall t \in T \quad (6.9)$$

$$B_{ipt} = \sum_w Q_{iwpt}^{crop \rightarrow IC} + \sum_j Q_{ijpt}^{crop \rightarrow bio}; \quad \forall i \in I, \forall p \in P, \forall t \in T \quad (6.10)$$

$$\sum_i Q_{iwpt}^{crop \rightarrow IC} (1 - \gamma) + CS_{wpt-1} (1 - \delta_t) = \sum_j Q_{wjpt}^{IC \rightarrow bio} + CS_{wpt}; \quad \forall w \in W, \forall p \in P, \forall t \in T \quad (6.11)$$

$$\sum_i Q_{ijpt}^{crop \rightarrow bio} (1 - \gamma) + \sum_w Q_{wjpt}^{IC \rightarrow bio} (1 - \gamma) + BS_{jpt-1} (1 - \delta_t) = \frac{C_{pjt}}{1 - h_p} + BS_{jpt}; \quad \forall j \in J, \forall p \in P, \forall t \in T \quad (6.12)$$

$$\sum_p C_{pit} = X_j \eta; \quad \forall j \in J, \forall t \in T \quad (6.13)$$

$$\sum_p BS_{jpt} \leq X_j \beta \eta; \quad \forall j \in J, \forall t \in T \quad (6.14)$$

$$\sum_p CS_{wpt} \leq Y_w \rho; \quad \forall w \in W, \forall t \in T \quad (6.15)$$

$$V_{ijt}^L \geq \sum_p \frac{Q_{ijpt}^{crop \rightarrow bio}}{cap^L}; \quad \forall i \in I, \forall j \in J, \forall t \in T \quad (6.16)$$

$$V_{iwt}^S \geq \sum_p \frac{Q_{iwpt}^{crop \rightarrow IC}}{cap^S}; \quad \forall i \in I, \forall w \in W, \forall t \in T \quad (6.17)$$

$$V_{wjt}^M \geq \sum_p \frac{Q_{wjpt}^{IC \rightarrow bio}}{cap^M}; \quad \forall w \in W, \forall j \in J, \forall t \in T \quad (6.18)$$

The objective function again minimizes the total costs (6.7). However, a richer range of costs are considered. Firstly, the costs of purchasing feedstock remains the same as before (6.7.1). Transportation costs now consider all different alternatives of reaching the biorefinery with a heterogeneous fleet (6.7.2) to (6.7.4). Finally, costs of stocking biomass is divided into stocking in the biorefinery main warehouses (4.7.5) and stocking in the intermediate-collector facilities, taking into account the extra costs of building them (4.7.6).

Constraint (4.8) ensures that only one biorefinery has to be set up. Constraints (4.9) guarantee resources availabilities given the production and exploitation factors. Constraints (4.10) define biomass from crops fields can go to either the biorefinery or the intermediate-collectors. Constraints (4.11) and (4.12) describe the intertemporal flows of biomass from crops fields to intermediate-collectors and the biorefinery. Note that those constraints consider depreciation in transportation and storage as well as the biomass humidity. Constraints (4.13) determine the monthly consumption of the biorefinery. Constraints (4.14) and (4.15) establishes the size of the warehouses for the biorefinery location and the intermediate collector, respectively. Finally, constraints (4.16) to (4.18) define vehicles utilization.

## 6. Results

Mathematical models were coded in the General Algebraic Modelling System (GAMS) and solved using CPLEX 14.1. They were run in an INTEL® i5 @2400 with 8 GB RAM. Justification of using the exact method is based on two factors. On the one hand, literature on facility location problems reveals exact method as the common methodology to solve this kind of problems. On the other hand, implementation of heuristic methodologies will not guarantee optimum solutions, and mainly used when exact methods fail. Thus, given the strategic nature of facility location problems it is preferred to obtain the highest quality solution rather than fast ones. For that reason, a time limit of 10 hours was set to each run. That limit was not exceed in any case.

24 scenarios were generated for each strategy (direct supply and intermediate-collector) based on biorefinery size and exploitation factor, as described in Table 6.9. Biorefinery size analysis ranges from 150,000 net tons of yearly consumption up to 500,000 tons. Those plant capacities are consistent with the total biomass production in the area. Moreover, exploitation factor was analyzed in cases they increase 50% and they decrease 50%.

Table 6.9. Scenarios  $S_i (i = 1, 2, \dots, 24)$  based on size and exploitation factor

Size	Exploitation Factor		
	Base = 1	1.5	0.5
150,000	S1	S2	S3
200,000	S4	S5	S6
250,000	S7	S8	S9
300,000	S10	S11	S12
350,000	S13	S14	S15
400,000	S16	S17	S18
450,000	S19	S20	S21
500,000	S22	S23	S24

Figure 6.7 shows the optimal emplacement for the biorefinery using either direct supply (DS) or intermediate-collectors (IC). Numbers can be looked up in the Figure 4. Most recurrent location for all alternative is the potential location number 20. However, significant differences arise if we pay attention carefully. According to the results, the Northwest of the study area seems to be an appropriate zone to locate the biorefinery because it accounts for almost all the optimal locations. Potential location 60 got best position three times corresponding to cases in which exploitation factor was extreme. Interesting insight is that location does not depend on biorefinery size due to a high effort in optimizing supply chain tactic decisions.

Total costs information is showed in Figure 6.8 where costs are divided into biomass costs, transportation costs and storage costs. All numbers are available upon request to the authors. Note that in the intermediate-collector strategy storage cost includes the cost of setting up the intermediate facilities. Intermediate-collector alternative is always a better choice in terms of costs. The lower depreciation rate as well as the flexibility of having intermediate warehouses allows reducing significantly the purchase invoice. On average, a reduction of 11% can be found in biomass costs. On the other hand, transportation costs and storage cost are much higher (41% and 49% higher, respectively) because more distance is driven as well as the additional cost of setting up the intermediate-collectors. As result, total reduction costs account for 2.68%, on average. Direct supply strategy is preferred in Scenario 13 (350,000 size and 1 exploitation factor), thought. An explanation could be that sufficient biomass is extended around location 20 that make it the direct supply a better choice. On the other hand, a 5% reduction costs is found in Strategy 5 due to the different biorefinery location and the high biomass availabilities as exploitation factor is set at 1.5.

A comparison between distances driven is given in Figure 6.9. As expected, 30% more distance is driven in the intermediate-collector strategy. As a result, in the direct supply strategy just 5.8 kilometers are driven for every ton required and 8.2 in the intermediate-collector one instead.

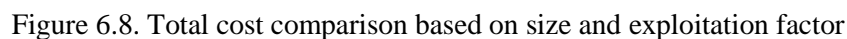
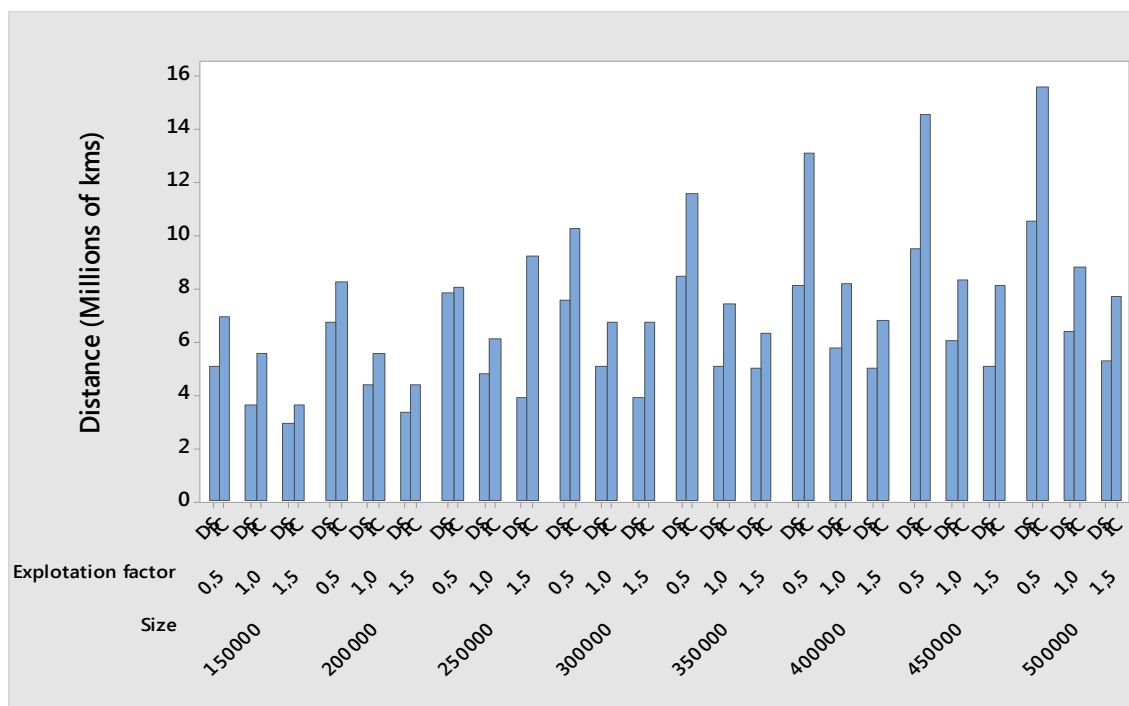


Figure 6.9. Distance driven comparison based on consumption and exploitation factor



## 7. Conclusions

Facility location problems deal with strategic decisions. They are made at the top management level of the company since their effects may compromise the development of the firm and even its own survival. Additionally, forthcoming tactical and operational decisions will depend on the previous strategic ones. For that reason, thoughtful analyses are required in order to evaluate properly their potential effects. Strategic Policy Evaluation aims to help decision makers in their strategic decisions by evaluating them among several scenarios.

A case study, in which a biorefinery has to be sited, is investigated in the regions of Navarre, La Rioja and Aragon (Northern Spain). Tactical decisions ranging from purchase policy, transport policy and storage policy are then carried out. Only local and limited biomass (winter cereal straw, corn straw, alfalfa, rape straw, and rice straw) can be harvested for feeding the biorefinery and two different and mutually exclusive storage strategies were assessed (1) direct supply from crops to biorefinery and (2) intermediate-collectors. Additionally, exploitation factors (the proportion of the total biomass available that effectively could be used for feeding a biorefinery) and biorefinery size (measured as biomass consumption) were used to generate several scenarios in which the strategic decision of location and all the tactic decisions must be taken.

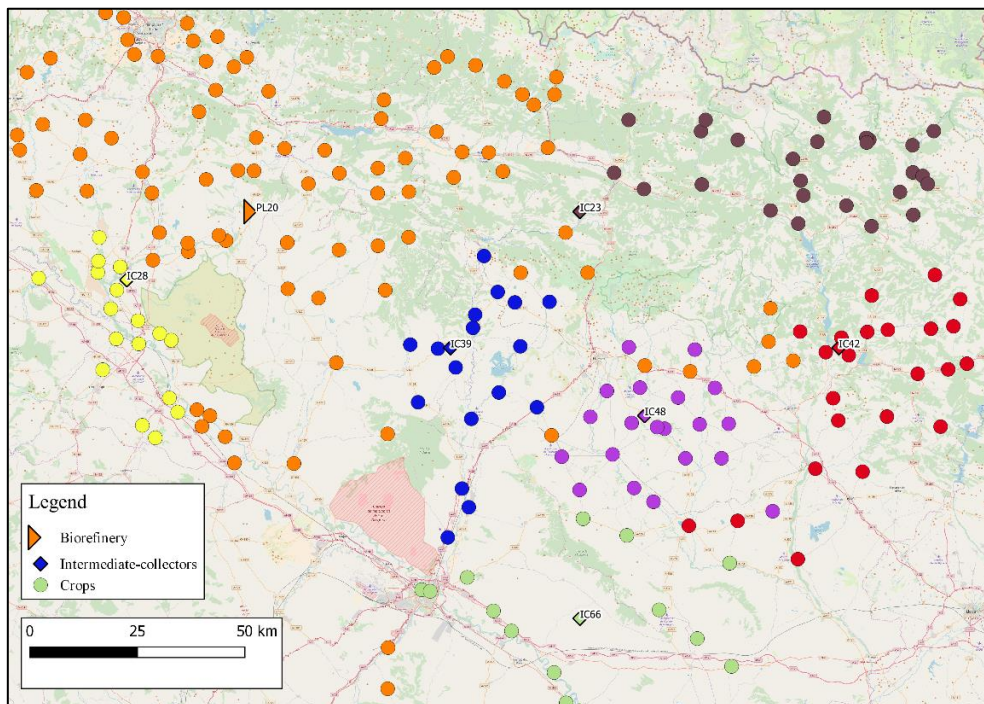
According to the results, biorefinery location should be sited in northwest study area as most of the potential locations obtained correspond to that area (see, for instance, PL10, PL20 or PL28). In this sense, the Figure 6.10 shows the solution corresponding to Scenario 7. In this case,

intermediate-collectors are set up in potential locations number 20 and 6. In Figure 6.10, crops fields are painted in the same color the intermediate-collector/biorefinery they are serving to. Moreover, there are some other crops fields that are not used.

Consequences of locating the biorefinery outside the “optimal area” can be computed. For instance, a wrongly number 75 location, in Southeast study area, would increase total cost by 15%. Once the location is fixed, significant differences arise between direct supply and intermediate-collector alternatives. The lower depreciation rates as well as the higher flexibility of having intermediate-collectors, make that alternative preferred over the direct supply strategy. Differences in terms of costs may rise up to 5% which represents about € 2.5 million yearly. Kilometers driven are significantly higher (about 30%) in the intermediate-collector alternative. This may incite a higher environmental impact that should be taken into account. The increasing concerns about environmental issues as well as the appearance of new environmental-taxes may compensate the savings of intermediate-collector alternative. If a green scenario had been contemplated, direct supply alternative would have been preferred and another location selected.

Internal purchase policy, transportation policy and storage policy can be analyzed within the scenarios. Thus, it is provided key information about critical biomass, crops and times. Therefore, decision makers could take advance in next negotiation processes with farmers. Moreover, a deeper transportation analysis can be performed pointing the optimal vehicle fleet combination (large, medium and small). Finally, the storage management is critical in that context. Information about stock levels over the year can be easily filter from the results.

Figure 6.10. Solution obtained when solving scenario 7







## CHAPTER 7.

# THE EFFECT OF ENVIRONMENTAL CRITERIA ON LOCATING A BIOREFINERY: A GREEN FACILITY LOCATION PROBLEM

*Underestimating facility location decisions may penalize business performance over the time. These penalties have usually been studied from the economic point of view, analyzing its impact on profitability. Additionally, the concern about obtaining sustainability is gaining importance, leading to a search for renewable energy sources to reduce greenhouse gas emissions. However, little attention has been paid to choosing a location considering environmental criteria. Thus, this work aims at determining a biorefinery location considering its impacts on natural resources. Therefore, a mixed integer linear programming (MILP) model has been developed, taking into account crop location and biomass production seasonality to obtain a proper location that minimizes environmental impact.*

This chapter is based in the following research contributions:

Serrano-Hernandez, A., Faulin, J., Belloso, J., and Sawik, B. (2017). The Effect of Environmental Criteria on Locating a Biorefinery: a Green Facility Location Problem. *Decision Making in Manufacturing and Services*, 11(1-2), 19-30.

Serrano-Hernandez, A., Faulin, J., Pintor, J. M., and Belloso, J. (2017). Determining an Optimal Area to Locate a Biorefinery under Economic and Environmental Criteria. *Transportation Research Procedia*, 22, 95-104.

## 1. Introduction

Biorefineries evolve rapidly to reduce the dependence from oil materials and their derivatives. That dependence may be solved by developing new energy alternatives from renewable resources. To this respect, biomass is seen as an important option to replace the use of fossil fuels, especially in the transportation sector. This substitution can be done because biorefineries transform biomass into liquid fuel in internal combustion engines (Börjesson et al. 2014) and electricity for electric vehicles (Juan et al. 2016). Thus, biofuels are considered a promising alternative to conventional fossil fuel in the short and medium term. The European Union is heavily dependent on imported energy resources, especially oil. Actually, 65% of oil consumption in EU is burnt in the transport sector, which contributes to increase greenhouse gas emissions (European Environment Agency, 2015). Most biorefineries have focused their interest and goals on bioethanol or biodiesel production contributing to such energy goal (Papendiek et al. 2016). However, biofuels are produced in large quantities but are sold at low prices making its profitability strongly dependent on market conditions, which are very difficult to control (oil and biomass prices) leading to a high volatility business. The biorefinery concept has evolved into new scenarios where biofuel production is complemented with other high-value chemical commodities in order to remedy that situation. Once it has been collected, biomass is converted into energy (for instance electricity and heat) and chemical commodities through biological and/or thermochemical processes that take place in the facility called the biorefinery (Cherubini et al. 2009).

Biorefinery location is a critical factor since many tactical and operational decisions (e.g. crops selection, purchase policies or stock policies) will depend on it (Daskin, 2015). The process of locating an industrial plant requires the analysis of several factors from many points of views: economic, social, technological, market, environmental, etc. Facility location decisions have a strategy nature. Generally, they have long lasting consequences and involve the whole company. Then, operational and tactics decisions are made based on the strategical infrastructure. For that reason, the scientific literature has tried giving a response to many questions related to the best place to locate a facility. Answers lie in the resolution of the Facility Location Problem (FLP).

Finally, this work makes a contribution in the scarce field biorefinery location, solving a real optimization problem within a rather new FLP variant: the Green FLP. The remainder of this chapter is structured as follows: Section 2 introduces related literature. The problem definition is presented in Section 3, and results of the computational experiments are presented and discussed in Section 4. Managerial insights are given in Section 5.

## 2. Related literature

Several FLP variants arise from the literature. For instance, [Montoya et al. \(2016\)](#) dealt with a multi-product FLP running a computational experiment over 288 instances with an average optimality gap of around 3%. Stochasticity approximation to location problems is described by [Serrano-Hernandez et al \(2016\)](#) and [Bieniek \(2015\)](#), where the randomness concept surges on production and demand difficulties in biorefinery analysis, respectively. [Ortiz-Astorquiza et al. \(2015\)](#) did a theoretical study on the multi-level FLP, which mainly consists of finding the best set of facilities to open for each level in order to maximize the total profit satisfying the demand of every customer. Another FLP variant is the Location Routing Problem in which a FLP and a Vehicle Routing Problem are considered at the same time [Koç et al \(2016\)](#). A rich multi objective FLP literature can be explored such as [Bashiri and Rezanezhad \(2015\)](#); and [Gutjahr and Dzubur \(2016\)](#). In this sense, it is particularly interesting the works from [Liu et al. \(2014\)](#); [Harris et al \(2014\)](#) and [Zhao and Verter \(2015\)](#) who took into account environmental-related objective functions. Finally, the recent work developed by [Martinez and Fransoo \(2017\)](#) reviewed the specific literature about Green Facility Location concluding the necessity of further research on that field in two directions: (i) incorporating new models to estimate a wider range of environmental impacts and (ii) assessing the energy efficiency of the facility itself.

FLP applications are unlimited, and there are some typical examples of them. Such is the case of the health care problems, in which health care centers (typically hospitals as pointed by [Chatterjee and Mukherjee, 2013](#)) should be located in order to maximize the assistance or coverage level. For instance, [Belien et al. \(2013\)](#) optimally placed some organ transplant centers. Few papers have considered biorefinery location from an analytical viewpoint. Most of them are supported by Geographical Information Systems such as [Yu et al. \(2014\)](#), using Net Present Value as function objective to be maximized ([Marvin et al, 2012](#)) as well as multiobjective programming where [You et al. \(2012\)](#), for instance, considered economic and environmental criteria. Finally, a remarkable work is described in the [Memisoglu et al.'s \(2015\)](#) paper in which a bioenergy supply chain is designed. They explicitly consider the location, production, inventory, and distribution problems to design the conjoint decisions of a biorefinery supply.

Exact solutions through Mixed Integer Linear Programming problems can be easily found in the literature as depicted by [Melo et al. \(2010\)](#). According to the authors, exact solution procedures represent more than a half of their reviewed literature. Heuristics algorithms have been developed for the FLP and many of its variants too. That is the case of [Lee and Lee \(2010\)](#) with a tabu search heuristic to solve a generalized hierarchical covering FLP. Similarly, [Aytug and Saydam \(2010\)](#) and [Shavandi and Mahlooji \(2006\)](#) solved the same problem with a genetic algorithm. Other examples are the next ones: [Bermand et al. \(2007\)](#) who developed a greedy

algorithm for a generalized maximal covering location problem; and [Sakakibara et al. \(2012\)](#) who simultaneously solve storage and delivery problem using a relax-and-fix heuristic.

### 3. Problem definition

In the same way that green logistics extends the traditional definition of logistic by explicitly taking into account other non-traditional external costs within all aspects of logistics; the Green FLP cares about environmental issues such as air pollution. Air pollution is caused by emission of air pollutants like particulate matter (PM), NO<sub>x</sub> and non-methane volatile organic compounds that affect people, vegetation, materials and global climate. Climate change or global warming impacts of road transport are, mainly, generated by emissions of greenhouse gases (GHG): carbon dioxide (CO<sub>2</sub>), nitrous oxide (N<sub>2</sub>O) and methane (CH<sub>4</sub>). Nevertheless, CO<sub>2</sub> is the dominant anthropogenic GHG, and the remaining GHG can be expressed as CO<sub>2</sub> equivalent (CO<sub>2</sub>e) ([Lera-López et al., 2014a](#)).

As previously said, the facility location problem is a strategic decision that will affect tactical and operational decisions when the facility is already running. For example, economically speaking, a facility should be placed in a city center, raising the area congestion which is used by the noisy and pollutant delivery trucks. People who will suffer from such nuisances due to the pure economic decision would *pay* for those external costs. For that reason, the Green FLP should take into account the whole environmental performance due to the location decision. That is, sustainability facility itself is out of the scope of this chapter since it is not related to location decisions.

Air pollution occurs when the fuel is burnt, therefore, everything that affect fuel consumption will affect emissions as well. Distance is the major fuel consumption determinant, however, there are many other factors that can be divided into four groups ([Demir et al. 2014](#)): (i) vehicle related, which include the curb weight or the type of fuel it uses. (ii) Environment related, such as the road gradient, the pavement type and even the temperature and altitude. (iii) Travel related, that would include the speed and acceleration or deceleration. Finally, (iv) Driver related such as driver aggressiveness and gear selection. From those factors, speed and load are the most important ones, being the reason why applying an average emission value per kilometer is not accurate. Later, road gradient plays an important role in fuel consumption, keeping in mind that downhill does not compensate up-hill. The remaining factors still affect marginally energy consumption.

The problem addressed in this article is stated as follows. In a 10,000 km<sup>2</sup> study area embracing the whole Autonomous Community of Navarre in Spain, we are given a set of crops that currently produce winter cereal (oats, barley, wheat, and corn), rape, rice, and alfalfa (those are the products

where the biomass comes from); being, all of them suitable for a lignocellulosic biorefinery. The Table 7.1 summarizes main characteristics regarding harvest times, humidity rate and market prices of the aforementioned biomasses (Department of Agriculture of Navarre, 2016).

Table 7.1. Biomass summary			
Biomass	Harvest times	Humidity (%)	Price (€/ton)
Winter Cereal	June-August	10	50-60
Corn	Nov- January	23	45-65
Alfalfa	March- October	58	75-105
Rape	July- August	10	65-85
Rice	October-Nov	25	50-70

The geographical scope is represented in the Figure 7.1, being the green dots the location of crops and the pink triangles the potential location to host the biorefinery (industrial parks). Since all the current biomass production cannot be collected for a biorefinery (Luo et al. 2010), for each product and crop an availability factor ( $\alpha$ ) is given in order to guarantee sustainability (soil, prices, animal feeding...). It means the proportion of the total resources availability that effectively could be used for feeding a biorefinery. Those exploitation factors were carefully chosen conjointly with the Navarrese Agricultural Department based on soil characteristics and current agricultural practice. Additionally, the biorefinery will sign long term supply contracts with providers in order to guarantee a continuous flow of biomass. Storage is allowed in origin and destination, that is, once collected, the biomass can wait in either production location or biorefinery warehouse with a known time-dependent depreciation rate. With regard to the location candidates, we use all the industrial parks in the study area that were able to host such a facility. Biorefinery capacity is determined from the supply side, accounting for 150,000 tons of dried biomass during the whole year, i.e. biorefinery processes monthly 12,500 tons of biomass. Finally, having the purpose of making comparisons, genuine data about biomass prices (of each product), transportation costs and storage cost are known.

A Mixed Integer Linear Programming (MILP) model is developed to determine the best location to place the abovementioned biorefinery and to determine the tactical and operational decisions (e.g. crops selection, purchase policies or stock policies) minimizing the environmental impact. Here, the environmental impact can be measured as the distance between the crops and the chosen biorefinery location. Due to the supply chain configuration, routing is not possible since vehicles leave the biorefinery empty and return full once a crop is collected. For the same reason, payload consideration in the model can be dropped out. Vehicle related factors are not



taken into account because their capacities are not considered in this model: there is only one type of truck with unlimited units. Finally, the study area has no significant road gradient differences. Sets are defined in the Table 7.2 whereas variable decision are depicted in the Table 7.3 and parameters are presented in the Table 7.4.

Figure 7.1. Geographical scope of the problem

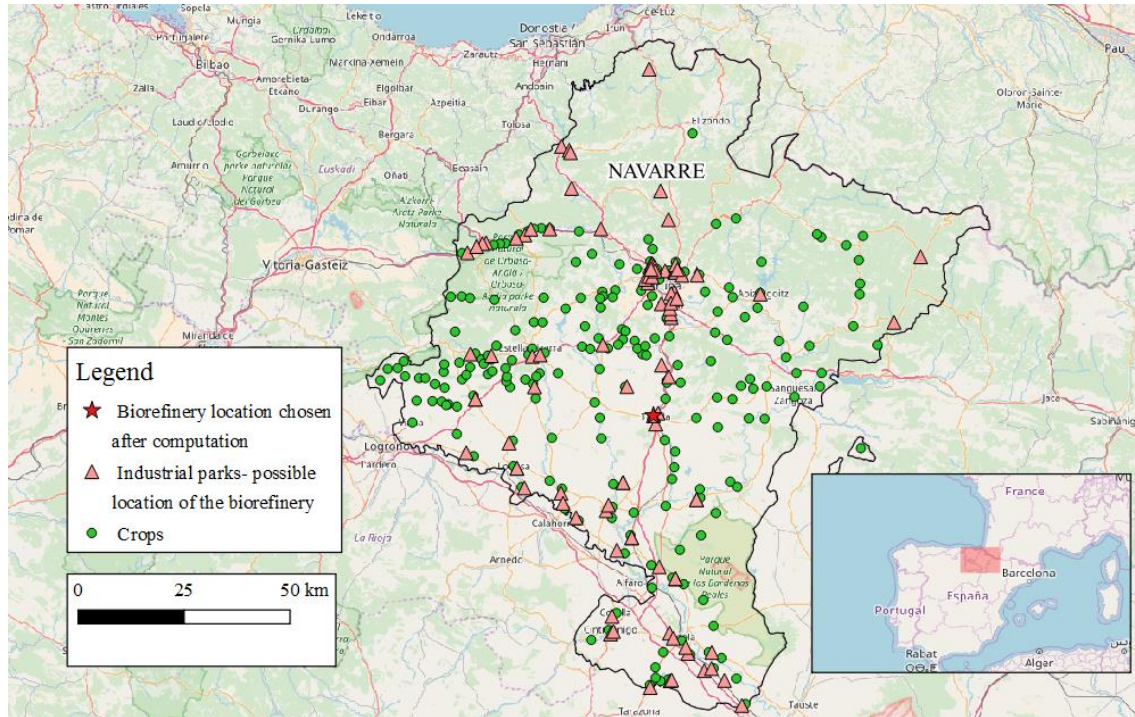


Table 7.2. Description of sets

Set	Description	Range
$I$	Set of crops	$i = 1, 2 \dots 221$
$J$	Set of potential biorefineries	$j = 1, 2 \dots 100$
$P$	Set of products	$p = oat, barley \dots alfalfa$
$T$	Set of months	$t = 1, 2 \dots 12$

Table 7.3. Description of variables

Variable	Description
$X_j$	1 if the biorefinery is built in potential location $j$ , 0 otherwise
$Y_{j,i,t}$	1 if at time $t$ , crop $i$ is selected to serve the potential biorefinery $j$
$Q_{i,j,p,t}$	Tons of product $p$ bought in crop $i$ at time $t$ to serve potential location $j$
$C_{p,i,t}$	Biorefinery $j$ consumption of product $p$ at time $t$
$S_{j,p,t}$	Stock corresponding to potential location $j$ of product $p$ at time $t$ in

Table 7.4. Description of parameters

Parameter	Description	Value	Unit
$h_p$	humidity of product $p$	10-58	%
$\theta_{pt}$	1 if product $p$ is available at $t$	0 or 1	-
$d_{ij}$	distance from crop $i$ to potential location $j$	0-200	Km
$\phi_p$	season duration of product $p$	2-8	Months
$q_{ip}$	total production of $p$ in $i$	0-10,000	Tn
$\alpha_{pi}$	exploitation factor of product $p$ in $i$	10-60	%
$\delta$	Depreciation rate during transportation	0.5	%
$\gamma$	Depreciation rate during storage	1	%

The problem formulation is as follows:

$$\min \text{Environmental Impact} = \sum_j \sum_i \sum_t Y_{jit} d_{ij} \quad (7.1)$$

Subject to:

$$\sum_j X_j = 1 \quad (7.2)$$

$$\sum_i Q_{pitj}(1 - \gamma) + S(1 - \delta) = \frac{C_{pjt}}{1 - h_p} + S_{ptj}; \forall p, \forall j, \forall t \quad (7.3)$$

$$\sum_p C_{pjt} = 12500X_j; \forall j, \forall t \quad (7.4)$$

$$Q_{p,i,t,j} \leq \text{AvaiBio}_{pit} Y_{jit}; \forall i, \forall p, \forall j, \forall t \quad (7.5)$$

$$Y_{jit} \leq X_j; \forall j, \forall t, \forall i \quad (7.6)$$

$$Y_{jit} \in \{0,1\} \quad (7.7)$$

$$X_j \in \{0,1\} \quad (7.8)$$

The constraint (7.2) determines that a single biorefinery can be placed. Restriction (7.3) describes storage flows taking into account product humidity and potential losses due to both transportation and storage. Constraint (7.4) establishes biomass that can be bought. Restriction (7.5) determines biorefinery capacity. Finally,  $\text{AvaiBio}_{p,i,t}$  in constraint (7.4) is the total biomass available of product  $p \in P$  in crop  $i \in I$  at month  $t \in T$ . Note that it depends on product seasonality and on the availability factor  $\alpha_{pi}$  to ensure that biorefinery is not going to take a huge portion of the total production ( $q_{pi}$ ) as recommended by Luo et al. (2010).

$$\text{AvaiBio}_{pit} = q_{pi} \alpha_{p,i} \frac{\theta_{pt}}{\phi_p} \quad (7.9)$$

Remaining constraints ensure whether a biorefinery is not built, no crop can be assigned to it (7.6) and force the variables  $Y_{j,i,t}$  (7.7) and  $X_j$  (7.8) to be binary variables.

#### 4. Results

The MILP model was coded in GAMS® software using a commercial solver to solve it running on a personal computer Intel ® Core™ i5-2430M CPU @ 2.40 GHz, and 4 GB RAM. The Figure 7.1 shows also the location chosen (red star). In order to get a better understanding of the results, the Figure 7.2 shows the sensitivity analysis of the environmental impact versus a cost minimization objective once the facility is already running. Note that (i) *Input* costs are made of the cost of buying the biomass. The (ii) *Transport* costs are made of the costs of transporting the biomass using fix and distance-payload based costs. That is the reason why transport costs are greater in the environmental minimization problem than in the costs minimization problem. Vehicles go to closer crops many times, increasing the fix cost of transportation. Finally (iii) *Stock* costs are made of the cost of storage the biomass. Therefore, the traditional cost minimization problem was optimized using additional cost-related parameters (Table 7.5) and the objective function (7.10), subject to the previous constraints.

Table 7.5. Description of cost related parameters

Parameter	Description	Value	Unit
$p_p$	price of product $p$	45-105	€
$FC$	transportation fix cost	8.23	€/Tn
$VC$	transportation variable cost	0.094	€/Tn/km
$s$	stock cost	0.945	€/Tn/month

$$\min Cost = InputCost + TransportCost + StockCost \quad (7.10)$$

Where:

$$InputCost = \sum_i \sum_p \sum_j \sum_t Q_{ijpt} p_p \quad (7.10.1)$$

$$TransportCost = \sum_i \sum_p \sum_j \sum_t (FC + VC d_{ij}) Q_{ijpt} \quad (7.10.2)$$

$$StockCost = \sum_p \sum_j \sum_t S_{jpt} s \quad (7.10.3)$$



In a first step, the Green FLP is solved giving us the best location among the tactical and operational policies (crops selection, purchase policies and stock policies) as well as its total costs. That is the point A in the Figure 7.2. In a second step, the location is fixed and the sensitivity analysis is applied by relaxing the environmental impact; actually, point B corresponds to the solution to the traditional cost minimization problem. This was made, by including the environmental impact as a new constraint for the traditional cost minimization model as described in Equation (7.11):

$$\text{Environmental Impact} = \sum_j \sum_i \sum_t Y_{jit} d_{ij} \leq \varepsilon \quad (7.11)$$

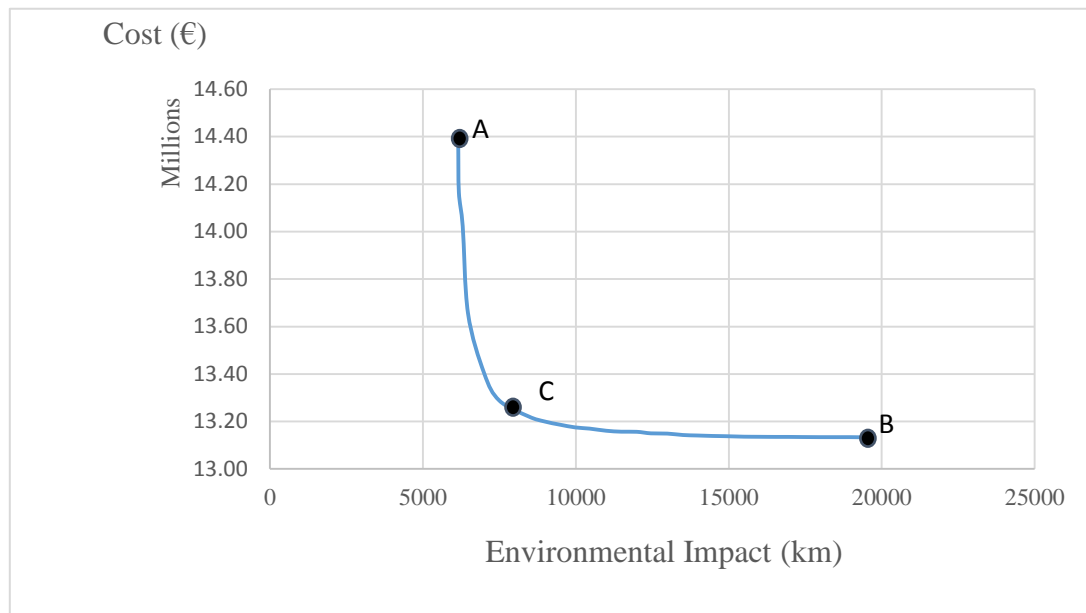
Where  $\varepsilon$  initially takes the value of the environmental impact obtained from the cost minimization problem and it is gradually diminished. Finally, note that in the economic valuation real biomass prices, transportation and storage costs have been taken into account. However, the reader should take in mind that the Green FLP is solved once to determine the location. Later, a traditional cost optimization model can be run but the location is already solved/fixed. Find in the Table 7.6 the numerical results for three different designs in terms of input, transport and storage management: the one minimizing distances (corresponding to the point A in the Figure 7.2), the one minimizing costs (corresponding to the point B in the Figure 7.2) and an arbitrarily chosen intermediate design (the point C).

Table 7.6. Summary of results

			Costs (€)			
			Input	Transport	Stock	Total
Min Envi Imp	Design A	6,158	11,227,480	2,371,526	783,055	14,382,061
	Design C	8,351	10,235,358	2,335,845	690,859	13,262,062
Min Costs	Design B	19,866	10,121,590	2,330,884	681,209	13,133,683

As can be seen in Figure 7.2, differences in terms of environmental impact and cost can be significant, being the decision maker able to choose among all the efficient line that corresponds to different tactical and operational configurations: crops selection, purchase policies and stock policies. Actually, the greener the supply chain is, the higher is its cost. Finally, note that there is a point C in which may not be worthy to keep greening the supply chain beyond that point, because, higher environmental impact reduction would involve great increases in cost. By doing so, minimum cost is not achieved (it would be point B) nonetheless a huge environmental impact is reached (57% reduction) by slightly increasing costs (around 1%).

Figure 7.2. Sensitivity Analysis Cost vs Environmental Impact



## 5. Conclusions

Facility location decisions are strategic having influence in forthcoming tactical and operational results. The underestimation of the importance of facility location decisions would lead them to being vulnerable to several threats that may jeopardize its survival. Facility Location Problem faces that situation in such a way potential locations are evaluated in order to choose a suitable place that may have to do with coverage objective (such as locating a hospital) or classical cost minimization. However, a Green Facility Location Problem is introduced in this chapter with the aim of choosing the location that minimizes overall environmental impact, that is taking into account tactical and operational decisions. A case study is carried out in which a biorefinery should be located minimizing its environmental impact. Biorefinery management would take advantage of sensitivity analysis in order to identify its key processes that allow them to empower their performance at both economic and environmental level. Management can adjust tactical and operational characteristic to choose the point they prefer in the sensitivity analysis, once the Green FLP have selected the location. Finally, a deeper analysis covering additional factors affecting environmental impact of facility location is expected in future research. Factors such as payload, road gradient and driver behavior would also play a determinant role in defining environmental-friendly location decisions.



**PART IV**

**RESEARCH ON ENVIROMENTAL  
IMPACTS OF TRANSPORTATION**



## CHAPTER 8.

# USING PROBIT AND TOBIT MODELS TO EVALUATE ENVIRONMENTAL COSTS IN ROAD TRANSPORTATION: A PRACTICAL APPROACH IN THE PYRENEES

*The neighbors of the usual routes of transportation suffer from the effects of the continuous movement of vehicles on the roads close to their homes. Although, it is possible to evaluate economically these externalities in many different ways, this chapter proposes the use of a contingent valuation method derived from a survey developed in the Spanish side of the Pyrenees. The respondents were asked for their willingness to pay (WTP) for different levels of pollution and noise presented in hypothetical scenarios. The survey also contains questions about socio-economic, ecological and demographic variables, among others, in order to enrich the WTP results. Therefore, this chapter focuses on extracting information from the results of surveys using two models (Tobit and Probit) to obtain estimations of environmental costs (pollution and noise). Noting that people with the characteristics depicted as ‘young, man, better educated, higher income and having more environmental concern’ are willing to pay more. A high detailed level is a special point in this chapter since those models allow us to compute meaningful marginal effects.*

This chapter is based in the following research contributions:

## 1. Introduction

Nowadays, transportation is a key sector of the economy and a major contributor to social and economic progress in the world due to its recent growth and obvious importance in modern societies. However, transportation also has negative consequences, for instance, noise, air pollution, vibration, etc. Moreover, indirect impacts include many other phenomena, such as, traffic jams and changes in citizens' behavior (i.e. anxiety and stress). All these negative influences are known as externalities which are, generally speaking, the indirect effects of consumption or production activity on the utility function of a consumer or a producer. Those effects are called indirect because they do not concern the agents involved in such an economic activity and they are not reflected in the price system (Laffont, 2008). Finally, externalities are deeply embedded and connected into a complex ecological and sociological network (Lera-López et al., 2014a).

Road transportation, as the primary mode of freight movement, is the largest source of freight-related CO<sub>2</sub> emissions in developed countries. That is, CO<sub>2</sub> emissions in transport sector and their contribution to climate change are one of the main problems to the sustainable management of logistic activities. *Externalities* should be considered to ensure the sustainable growth of transportation in the world.

### 1.1. Geographical Scope

The Pyrenees are a natural barrier between France and Spain where about 140,000 vehicles crossed it daily in 2011, of which 20% were freight trucks (Spanish-French Observatory of Road Transport at the Pyrenees, 2017). The Pyrenees are a mountain range crossed by with a dense road transportation, whose busiest routes are located at its geographical extremes (La Junquera in Catalonia and Irun in the Basque Country). As result, a funnel effect occurs in those two areas being greatly impacted with consequences for the environment as it has previously been discussed.

Thus, the concern of our society for environmental issues, and specifically, issues related to transportation, is clear. Anything that helps us to evaluate the environmental damages and individuals' WTP to avoid those externalities plays an essential role. Therefore, this work aims to analyze the determinants of individuals' WTP in a broad sense, but focusing on the particular case of residents in the two main routes crossing the Pyrenees, that search for a reduction in noise

and air pollution due to transportation externalities. These routes, which pass through some towns and villages, include from highways with heavy traffic to small national routes.

This chapter is organized into four main sections. Following this introduction (section 1), section 2 describes and justifies the used methodology while section 3 presents the main results of the paper. Finally, the conclusion section describes the main ideas, policy implications, and potential avenues for future research.

## 2. Methodology and literature review

### 2.1. The Contingent Valuation Method

Generally speaking, the Contingent Valuation Method (CVM) uses a sequence of questions in order to elicit individuals' preferences for public goods or environmental services. Trying to figure out what they would be willing to pay for specific improvements in them is the key issue. The aim, therefore, is to determine the economic value that the individual perceives from them. This is reached by presenting a hypothetical market where the consumers have the opportunity to purchase the 'good' in question. Actually, it is known as contingent because such valuation is contingent on the hypothetical scenario that is presented to the individual (Mitchell and Carson, 1989). The use of this method has many advantages in this study as an economic valuation measure of nonmarket goods. However, it is not free from drawbacks, such as, the inclusion of bias caused by the starting bid provided to the respondent. Controlling that variable is, therefore, very important to avoid that bias. CVM is a common technique in the valuation of externalities which many papers on air quality and/or noise assessments have been employed to reach their results (e.g. Alberini and Chiabai (2007) and Shih et al (2012), for air quality or Barreiro et al. (2005) and Durán and Vázquez (2009), for noise).

The basic idea behind CVM is linked with utility theory (Quentin et al., 2004). That is, given a utility function  $U_0(\cdot)$  which depends on the actual polluted scenario  $S_0$  and income  $m_0$  and other utility function  $U_1(\cdot)$  which depends on the cleaner proposed scenario  $S_1$  and some income  $m_1$  being  $m_0 = m_1 + WTP$ ; the WTP that the respondent would say in the CVM will be the one that satisfy:

$$U_0(S_0, m_0) = U_1(S_1, m_0 - WTP) \quad (8.1)$$

Therefore, satisfaction in both scenarios (actual and contingent) has to be the same taking into account income will be lower (WTP) in the contingent one. Of course, here WTP is a



subjective measure that depends on many factors and may (will) differ from individuals. Actually, in this chapter we are going to analyze why and how much WTP varies.

## 2.2. The Questionnaire

Given the above, it is evident that questionnaires play a crucial role in the correct application of CVM. Following the recommendations of [Mitchell and Carson's \(1989\)](#) methodology, we developed a questionnaire divided into three main sections. In the first questionnaire section, we developed a relatively extensive introduction to ensure that respondents understood the problem under consideration. Firstly, the respondents are selected according to their proximity to the main road (zone A or B whether they are closer than 100m to that road or not, respectively). The second section describes the contingent valuation process itself, with questions about the respondent's WTP to change the current scenario to another one with lower levels of pollution/noise. To reach this, in the case of noise, the respondents were asked to listen to a recorded sample with different noise levels. Later, they were asked to listen another acoustical sample simulating a hypothetical scenario. In the case of the air pollution, the hypothetical scenario is represented by a significant reduction in number of people suffering from respiratory or coughs problems. [Table 8.1](#) summarizes those scenarios.

Table 8.1. Scenarios proposed

Issue	Scenario
Noise	40% noise reduction
Air pollution	50% number of people reduction suffering from respiratory problems due to air pollution

This section also contains control questions to find out possible reasons for unwillingness to pay ([Jorgensen et al., 2001](#)), that is WTP equals to zero. The aim is to detect the so-call zero protest ([Lo et al, 2015](#)) because there are respondents that even valuing positively the proposed scenario, they are not willing to pay anything because they either think that are already paying enough taxes or feel no responsibility for noise /air pollution ([Dziegielewska and Mendelsohn, 2005](#)). Due to the fact that zero responses represent a high percentage of the answer, we have to treat them accordingly ([Halstead et al, 1992](#)). Protest zeros are often removed from the database. In order to reduce the bias caused by their inclusion. The drawback of this method is that we can lose potentially useful information and would also include some selection bias because we would be assuming that the WTP of this protest group would be the same as those who would not respond to the survey. Since we determine which zeros are protest or genuine ones, we took it into account

on our estimations process. Finally, the third section of the questionnaire contains classifying questions about environmental topics and the main statistical characteristics of the respondent.

An extremely important issue in WTP surveys is that we need anchor values (starting bids) to be taken as reference. Otherwise, different WTP would be extreme and contradictory with their determinants. Thus, respondents are asked whether they are willing to pay that starting amount of money or not. Then, they are again asked for their real WTP, which can differ or not from the starting bid. Of course, these anchor values or starting prices have been carefully chosen, taking into account several papers which use the CVM. In Poland, [Dziegielewska and Mendelsohn \(2005\)](#) got €16 WTP for a 25% reduction people affected by air pollution and €20 for a 50%. Wang and Mullahy (2006) obtained €14.30 WTP for a 50% reduction of air pollution in China. In Spain, [Martín et al. \(2006\)](#) and [Barreiro et al. \(2005\)](#) got €7.20 and €30 WTP respectively for a noise nuisance reduction and [Durán and Vázquez \(2006\)](#) found €48 WTP for reducing people affected by air pollution. Taking all the previous studies into account, we divided our sample into 3 subsamples. Each of them with a different starting price set in €15, €30, €45. The payment vehicle was a compulsory annual tax per household.

### 2.3. Database

The data collection was made in December 2012 by conducting telephone surveys with 1612 persons who live in cities (most of them, very small) along the main roads crossing the Pyrenees. Table 8.2 presents information about total sample. Table 8.3 and Table 8.4, represent the sample without zero protest. Table 5 make a comparison between them and include information about the proportion of payment once removed the non-genuine zeros.

Table 8.2. Details of the total sample

Region	The Basque Country						Catalonia					
Zone	A			B			A			B		
Starting bid (€)	15	30	45	15	30	45	15	30	45	15	30	45
Questionnaire type	1	2	3	4	5	6	7	8	9	10	11	12
Number questionnaires	132	132	126	140	146	125	145	138	122	138	148	120

Table 8.3. Air pollution sample excluding *zero protest*

Region	The Basque Country						Catalonia					
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Zone	A			B			A			B		
Starting bid (€)	15	30	45	15	30	45	15	30	45	15	30	45
Questionnaire type	1	2	3	4	5	6	7	8	9	10	11	12
Number questionnaire	118	114	108	124	130	110	132	127	117	131	143	116

Table 8.4. Noise sample excluding *zero protest*

Region	The Basque Country						Catalonia					
Zone	A			B			A			B		
Starting bid (€)	15	30	45	15	30	45	15	30	45	15	30	45
Questionnaire type	1	2	3	4	5	6	7	8	9	10	11	12
Number of questionnaire	113	108	99	128	128	106	128	125	108	122	141	111

Table 8.5. Comparison between different samples of the respondent population

	The Basque Country	Catalonia	Total
Air pollution 'zero protest'	12.10%	5.54%	8.80%
Noise 'zero protest'	14.86%	9.37%	12.10%
Air pollution payment	42.75%	47.12%	45.03%
Noise payment	31.23%	34.82%	33.10%

## 2.4. Description of variables

Table 8.6 shows all variables selected as potential WTP determinants. Apart from the starting bid, the remaining variables are divided into two types; variables related to environmental concerns and variables related to sociodemographic ones.

Table 8.6. Variables

Variable	Description
Price	Starting price
<i>Environmental variables</i>	
Noise perception	Noise level heard in the residence area (1 to 5, 5 more noisy)
Air pollution perception	Air quality in the residence area (1 to 5, 5 higher quality)
Noise nuisance	Nuisance due to traffic noise (1 a 5, 5 more nuisance)
Air pollution nuisance	Nuisance due to the air traffic pollution (1 a 5, 5 more nuisance)
Hearing problems	Having hearing problems (0:no, 1:yes)
Smoker	Being smoker (0:no, 1:yes)
Health	Health level (1 to 5, 5 worse health)
General concern	General level of environmental concern due to the noise level and the air quality in the residence area (1 to 5, 5 higher concern)
<i>Sociodemographic variables</i>	
Region	1: The Basque Country, 0: Catalonia
Age	Age
Gender	Gender (0: woman, 1: man)

Income	Income level (1 high level, 2 medium level, 3 low level)
Educational level	1 to 4, (4 university level)
Zone (A o B)	Distance to the main road (0: more than 100 meters (A), 1: less than 100 meters (B))

## 2.5. Models

To determine the influence of the initial price offered to know whether the respondent is willing to pay that amount, we use a probit model for both analyzed externalities (noise and pollution) using the [Equation \(8.2\)](#):

$$y_i^* = \beta' x_i + u_i, \quad i = 1, 2, \dots, n \quad (8.2)$$

Being  $x_i$  the proposed price vector (15, 30 or 45) and  $u_i$  is the error term. But instead of observing  $y_i^*$ , we observe a binary variable indicating the sign of  $y_i^*$ , vector of binary variables that, for each individual, takes the value 1 if s/he is willing to pay the price initially indicated and 0 otherwise as described in the [Equation \(8.3\)](#):

$$y_i = \begin{cases} 1 & \text{if } y_i^* > 0 \\ 0 & \text{if } y_i^* \leq 0 \end{cases}, \quad i = 1, 2, \dots, n \quad (8.3)$$

Then, we analyze the influence of determinants on the probability that the individual is willing to pay some positive amount. We use, as before, a probit model [\(8.4\)](#):

$$z_i^* = \gamma' w_i + v_i, \quad i = 1, 2, \dots, n \quad (8.4)$$

Now,  $w_i$  is the vector of explanatory variables and  $v_i$  is the error term. Again, instead of observing  $z_i^*$ , we observe a binary variable indicating the sign of  $z_i^*$ , vector of binary variables that, for each individual, takes the value 1 if it is willing to pay some positive amount and 0 otherwise as described in the [Equation \(8.5\)](#):

$$z_i = \begin{cases} 1 & \text{if } z_i^* > 0 \\ 0 & \text{if } z_i^* \leq 0 \end{cases}, \quad i = 1, 2, \dots, n \quad (8.5)$$

Finally, we analyze the influence of these determinants on the amount the respondent is finally willing to pay. The problem is that in this type of questionnaire, respondents often give the answer 0 for WTP as a way of showing protest towards the possibility of paying higher taxes. If we ignore this fact, the results of the estimates will be biased and inconsistent. Therefore we should *censor* somehow those zeros. The Tobit [\(8.6\)](#) and [\(8.7\)](#) model provides the solution to this problem.

$$WTP_i^* = \delta' w_i + d_i, \quad i = 1, 2, \dots, n \quad (8.6)$$

$$WTP_i = \max(0, WTP_i^*), \quad i = 1, 2, \dots, n \quad (8.7)$$

Where  $WTP_i^*$  is the latent variable of the willingness to pay,  $WTP_i$  the amount payable is expressed by each of the respondents,  $w_i$  the vector of independent variables and  $d_i$  the error term.

### 3. Results

The results are presented in [Table 8.7](#) and [Table 8.8](#) for noise (both including and not including zeros protest); and [Table 8.9](#) and [Table 8.10](#) for air pollution (both including and not including zeros protests). Those tables are organized as follows:

- First column contains the starting bid analysis in which we look for the influence of the proposed initial price in the probability to pay that starting bid.
- Second column includes the probit analysis. Such an analysis allows us to identify factors that make individuals to pay any amount, i.e. the propensity to pay.
- Third column covers the tobit analysis in which we aim to discover those factors that affect to the WTP.
- Inside the three columns, some other pieces of information are provided. Since we are dealing with non-linear models, coefficient label ( $\hat{\beta}$ ) gives the signs of the marginal effects of each factor as well as their statistical significance, which is reported in p-value label (i.e. the probability of such an effect to be zero). Again, due to the fact on non-linearity, factor marginal effects depend on the level of the factors, therefore, we must compute it at interesting values of them. So, the slope at the mean label (marginal effect) was calculated by taking the mean values of the regressors. In the probit model it is computed as follows, marginal effects are computed as follows, being  $X$  the vector of factors and  $\phi(\cdot)$  the standard normal probability density function:

$$\frac{\partial E(Y|X)}{\partial X} = \phi(\bar{X}'\hat{\beta})\hat{\beta} \quad (8.8)$$

Whereas in the tobit model, being  $\hat{\sigma}$  the regression standard error (provided at the bottom of the tobit section tables, as sigma), it is computed as,

$$\frac{\partial E(Y|Y > 0, X)}{\partial X} = \phi\left(\frac{\bar{X}'\hat{\beta}}{\hat{\sigma}}\right)\hat{\beta} \quad (8.9)$$

On the other hand, the slope at zero label has been used for those regressors that cannot take average values (gender, region ...). Therefore, being  $\Phi(\cdot)$  the normal cumulative distribution function, marginal effects are computed in the probit model as the value of  $\Phi(X'\hat{\beta})$  for each of those binary factors when  $X = 1$  and the other regressors equal to fixed values minus  $\Phi(X'\hat{\beta})$  for each of those binary factors when  $X = 0$  keeping the rest regressors equal the same fixed values. Likewise, in tobit model such effects are computed as  $\Phi\left(\frac{X'\hat{\beta}}{\hat{\sigma}}\right)$  for each of those binary factors when  $X = 1$  and the other regressors equal to fixed values minus  $\Phi\left(\frac{X'\hat{\beta}}{\hat{\sigma}}\right)$  for each of those binary factors when  $X = 0$  keeping the rest regressors equal the same fixed values.

- Probit and tobit models are estimated using Maximum Likelihood Estimation (MLE), thus, at the bottom of tables it is provided pieces of information regarding the regression such as the value achieved in the log-likelihood maximization process, the Likelihood Ratio (LR) to test global significance (chi squared row) and the probability of not having regression (prob. row). That is, if log-likelihood of unrestricted model is approximately the same as the log-likelihood of the restricted model (the model without explanatory variables) the probability of not having regression should be high (at least, higher than 10%).

The analysis was performed by GRET, a software package for econometric analysis (<http://gretl.sourceforge.net>) on a personal computer with Windows 7 and Intel Core 2 Quad Q6600 2.40 GHz processor and 4 GB of RAM. The results give, in addition to coefficients and p-values, two pieces of information regarding the marginal effects. The discussion of results is divided into three parts: the first one is about the effect of the starting bid, the second in which we analyze the propensity to pay (whether to pay or not determinants), and finally, the WTP (the amount determinants).

### 3.1. Starting bid

Firstly, we were interested in the influence of the proposed initial price in the probability to pay that price. As expected, in all cases the sign is negative and highly significant, since the higher starting price (15, 30, 45), the lower probability to pay. However it is interesting knowing how this probability varies when a marginal change in the price initially proposed occurs. In this regard, it is estimated that, on average, the probability of someone would be willing to pay the

initially proposed price is reduced between 0.3% and 0.4%, pollution and noise respectively, for each extra euro increase. No significant difference arise if we remove the protest zeros.

Table 8.7. Noise results whole sample.

NOISE	Initial Price			Probit				Tobit			
	Coeff	Slope	P Value	Coeff	Slp. $\bar{x}$	Slp. 0	P Value	Coeff	Slp. $\bar{x}$	Slp. 0	P Value
Constant	-0.3108		0.0004***	-0.4623			0.0023***	-18.120			0.0007***
Starting Bid	-0.011	-0.00361	0.0000***								
<i>Environmental Variables</i>											
Noise perception				0.1333	0.04518		0.0001***	4.9575	2.40877		0.0000***
Noise nuisance				0.0024	0.00081		0.8052	0.1487	0.07225		0.6941
Hearing problems				-0.0037	-0.00125		0.9701	-0.0353	-0.01715		0.9915
Road externalities concern				0.0001	0.00003		0.9640	-0.0067	-0.00326		0.9359
<i>Sociodemographic Variables</i>											
Region											
Zone				-0.1586	-0.05376	-0.06288	0.0195**	-3.6812	-1.78863	-1,86507	0.0979*
Sex				0.0770	0.02610	0.02962	0.2614	1.2057	0.58583	0,57764	0.5959
Age				0.1846	0.06257	0.07507	0.0069***	6.6198	3.21645	3,01434	0.0036***
Income				-0.009	-0.00301		0.000***	-0.3079	-0.14960		0.0000***
No studies				-0.0017	-0.00057		0.0483**	-0.0724	-0.03518		0.0117**
Primary studies				0.0044	0.00149	0.00149	0.6021	2.2633	1.09970	1,11202	0.5057
Secondary studies				0.0527	0.01786	0,01635	0.0809*	-4.4354	-2.15509	-2,25592	0.0588*
Health				0.0725	0.02457	0,02383	0.2668	2.3437	1.13877	1,13036	0.2741
				-0.0036	-0.00122		0.1410	-0.1188	-0.05772		0.1586
Log-Likelihood		-921.9381				-936.9838				-2880.516	
Chi-Squared		15.8487				71.863				72.90084	
Prob.		0.0001***				0.0000***				0.0000***	
Sigma										35.3585	

Note: \*  $p < 0.10$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.01$



Table 8.8. Noise results excluding zero protest.

NOISE EXCLUDING ZERO PROTEST	Initial Price			Probit				Tobit			
	Coeff	Slope	P Value	Coeff	Slp. $\bar{x}$	Slp. 0	P Value	Coeff	Slp. $\bar{x}$	Slp. 0	P Value
Constant	-0.2020		0.0274**	-0.5972			0.0002***	-20.268			0.0000***
Starting Bid	-0.0111	-0.00385	0.0002***								
<i>Environmental Concern Variables</i>											
Noise perception				0.2305	0.08253		0.000***	7.4074	4.39567		0.000***
Noise nuisance				0.0103	0.00368		0.4297	0.3782	0.22443		0.4199
Hearing problems				-0.0256	-0.00916		0.8040	-0.6849	-0.40643		0.8309
Road externalities concern				-0.0001	-0.00003		0.9678	-0.0126	-0.00748		0.8768
<i>Sociodemographic Variables</i>											
Region											
Zone											
Sex				-0.1346	-0.04818	0.05133	0.0615*	-2.4009	-1.42473	-1.45705	0.2706
Age				0.1058	0.03787	0.03615	0.1433	1.6401	0.97326	0.95807	0.4601
Income				0.2063	0.07385	0.06236	0.0041***	6.7920	4.03048	3.80663	0.0020***
No studies				-0.0112	-0.00400		0.0000***	-0.3219	-0.19102		0.0000***
Primary studies				-0.0015	-0.0005		0.0926*	-0.0638	-0.03786		0.0230**
Secondary studies				0.0084	0.00300	0.00298	0.9373	0.8477	0.50304	0.50262	0.7999
Health				-0.1088	-0.03895	-0.04046	0.1356	-3.8218	-2.26792	-2.32250	0.0957*
				0.1051	0.03762	0.03701	0.1285	3.1436	1.86546	1.82006	0.1322
				-0.0037	-0.00132		0.1479	-0.1142	-0.06777		0.1625
Log-Likelihood		-858.1887			-848.1681				-2784.377		
Chi-Squared		14.6425			102.084				104.7321		
Prob.		0.0001***			0.0000***				0.0000***		
Sigma									33.0683		

Note: \* p<0.10, \*\* p<0.05, \*\*\* p<0.01

Table 8.9. Air pollution results whole sample.

AIR POLLUTION	Initial Price			Probit				Tobit			
	Coeff	Slope	P Value	Coeff	Slp. $\bar{x}$	Slp. 0	P Value	Coeff	Slp. $\bar{x}$	Slp. 0	P Value
Constant	-0.0962		0.2475	0.1109			0.5314	1.8322			0.7094
Starting Bid	-0.0071	-0.00270	0.0068***								
<i>Environmental Concern Variables</i>											
Air pollution perception				-0.0501	-0.01923		0.0554*	-1.1720	-0.49694		0.1076
Air pollution nuisance				0.0495	0.01900		0.0238**	1.5759	0.66820		0.0103**
Smoker				0.0445	0.01708		0.5464	0.3570	0.15137		0.8630
Road externalities concern				0.0172	0.00660		0.5949	0.8477	0.35944		0.3458
<i>Sociodemographic Variables</i>											
Region				-0.2366	-0.09085	-0.09321	0.0005***	-5.1739	-2.19380	-2.36254	0.0064***
Zone				0.0345	0.01324	0.01358	0.5304	-0.0468	-0.01984	-0.01986	0.9797
Sex				0.2061	0.07914	0.07801	0.0017***	6.8608	2.90907	2.66981	0.0002***
Age				-0.0067	-0.00257		0.0000***	-0.1957	-0.08298		0.0000***
Income				-0.0014	-0.00053		0.0635**	-0.0587	-0.02489		0.0081***
No studies				0.0305	0.01171	0.01168	0.7522	-0.1654	-0.07013	-0.07015	0.9501
Primary studies				-0.1088	-0.04177	-0.04264	0.0978*	-2.7081	-1.14827	-1.17773	0.1438
Secondary studies				0.0793	0.03045	0.03079	0.2030	2.9368	1.24524	1.20328	0.0834*
Health				0.0084	0.00326		0.7107	0.2584	0.10956		0.6882
Log-Likelihood		-1067.026			-1040.962				-3649.390		
Chi-Squared		7.3214			68.9264				78.48037		
Prob.		0.0068***			0.0000***				0.0000***		
Sigma									31.2816		

Note: \* p<0.10, \*\* p<0.05, \*\*\* p<0.01

Table 8.10. Air pollution results excluding zero protest.

AIR POLLUTION EXCLUDING ZERO PROTEST	Initial Price			Probit				Tobit			
	Coeff	Slope	P Value	Coeff	Slp. $\bar{x}$	Slp. 0	P Value	Coeff	Slp. $\bar{x}$	Slp. 0	P Value
Constant	0.0189		0.8271	0.1410			0.7336	3.2270			0.7607
Starting Bid	-0.0078	-0.00304	0.0043***								
<i>Environmental Concern Variables</i>											
Air pollution perception				-0.1675	-0.06633		0.0013***	-3.3597	-1.49211		0.0102**
Air pollution nuisance				0.1179	0.04668		0.0010***	3.1398	1.39445		0.0004***
Smoker				0.2207	0.08739		0.0328**	4.9345	2.19152		0.0538*
Road externalities concern				0.0291	0.01152		0.4759	1.2074	0.53623		0.2526
<i>Sociodemographic Variables</i>											
Region				-0.1194	-0.04728	-0.04898	0.1830	-0.5908	-0.26239	-0.26465	0.7948
Zone				0.0076	0.00305	0.00303	0.9277	-0.3994	-0.17738	-0.17842	0.8542
Sex				0.2010	0.07959	0.07215	0.0196**	7.1077	3.15668	2.87963	0.0012***
Age				-0.0071	-0.00281		0.0181**	-0.2200	-0.09771		0.0050***
Income				-0.0446	-0.01766		0.3378	-1.4435	-0.64109		0.2201
No studies				-0.0037	-0.00146	-0.00146	0.9693	-1.215	-0.53961	-0.54060	0.6264
Primary studies				-0.0911	-0.03607	-0.03722	0.1723	-1.9254	-0.85511	-0.87114	0.2687
Secondary studies				0.0965	0.03821	0.03563	0.1325	3.2187	1.42949	1.37516	0.0463**
Health				0.08161	0.03231		0.1138	1.8709	0.83091		0.1491
Log-Likelihood		-995.0324					-985.6873				-3703.561
Chi-Squared		8.17784					53.1499				60.01205
Prob.		0.0042***					0.0000***				0.0000***
Sigma											29.2787

Note: \* p<0.10, \*\* p<0.05, \*\*\* p<0.01

### 3.2. *Propensity to pay*

Probit models were used in order to analyze the probability that an individual was willing to pay any amount for the externality in question.

#### 3.2.1. *Noise*

Regarding the first externality considered, the perception of noise is significant in environmental concern variables. It is estimated that the additional degree of perceived noise would increase the propensity to pay by about 4.5%. Note that noise annoyance is not significant. This may be due to the fact that the respondents did not adequately distinguish the difference between perceiving and annoying, or they are already fairly accustomed to the noise and do not consider it annoying.

However, region, age, gender, income and education level variables influence on the propensity to pay. Thus, living in the Basque Country or Catalonia is a determining factor of being willing to pay to reduce noise levels; being more likely to pay in Catalonia than in the Basque Country. Similarly, the older an individual is, the lower is his/her propensity to pay (-0.3% per additional year). A man is also more likely to pay and, as expected, the higher the level of income is, the greater is his/her propensity to pay. Finally, it seems that the education level of the population, once the basic education is obtained, may be a decisive factor. To sum up, there is a greater probability to pay in the group of young people, men, resident in Catalonia, having higher incomes and, at least, primary studies.

The results change slightly if we remove from the sample the zeros protest. As before, the perception of noise was a determinant, but now that probability increases to 8.25% per additional level of noise perception. The other sociodemographic variables that were previously significant, keeping their significance and slightly sharpen their influences.

#### 3.2.2. *Air pollution*

Similar results are obtained analyzing air pollution determinants. Unlike the noise, air pollution nuisance is significant in the inclination of people to pay. The explanation for this may be that the symptoms caused by pollution are much clearer than those caused by noise (e.g. cough, difficulty breathing, odor, etc.). As with noise, living in the Basque Country ‘penalizes’ the propensity to pay to reduce pollution levels (on average, a person living in the Basque Country reduces its chance to pay more than 9%). Again, being male increases the probability of payment. Similarly, younger people are more willing to pay. To sum up, without regard to subjective variables, the greater likelihood of payment is on young people, men and residents in Catalonia.

When analyzing the results for air pollution removing protests many differences arise. The variables related to perception and nuisance of pollution are increased significantly (6.6% and 4.6% respectively for an additional degree). Also, being a smoker increases by 8% the probability to pay. The reason for this may lie in the increasing awareness of the dangers of smoking, feeling somehow responsible for that damage and being therefore more likely to pay. The remaining variables are no longer significant: it seems that the ‘protesters’ are concentrated in one region, Basque Country. Thus, the typical payer in this analysis is a young male smoker with concerned about air pollution man.

### *3.3. Amount to be paid*

Not only is the propensity to pay important as previously analyze, but also the payment itself (i.e. in monetary terms). So, the second step is how the determinants affect the amount to be paid. Tobit model is now called.

#### *3.3.1. Noise*

The same factors that influenced the propensity to pay influence also that amount. So the perception of noise is highly significant in environmental concern terms; and the region, sex, age, income and education variables are critical in sociodemographic terms. If we look at the marginal effects, on average an additional degree of perceived noise increases the amount to be paid at € 2.40. Residents in the Basque Country are willing to pay € 1.86 less than those who live in Catalonia. Similarly, men are willing to pay € 3 more than women and it is paid about 15 cents less for each additional year. Additionally, income has a positive effect, the higher the income, the higher the amount to pay. The effect of primary studies tells us that people at this level pay € 2.25 less than those with a higher level. Removing the zeros protest responses implies no longer region significance. The other variables remain influential and sharpen its effects.

#### *3.3.2. Air pollution*

Turning to the second externality, we see that, in general, those variables that were significant in determining whether an individual was willing to pay, they are again significant in the amount to be paid. The nuisance of pollution is the key environmental issue as additional degree would imply an increase of the amount to pay by € 0.67. Nevertheless, the region, sex, age, income and education variables determine the amount payable in terms of sociodemographic variables. Living in the Basque Country imply to pay € 2.36 less than reside in Catalonia. Likewise, a man would pay € 2.67 more than a woman and for each additional year it is paid 8 cents less. Thus, income, as in the previous cases, influences the amount payable in a positive sense. If we focus on the results of air pollution once debugged the effect of zeros protest, the results are strikingly

different. Environmental concern variables become significant, with the exception of general concern. It is noteworthy that a perception of greater air pollution implied paying more than € 1.5, while it was not significant in the analysis without eliminating zeros protest.

### 3.4. General Results

Table 8.11 and Table 8.12 give the general results.

Table 8.11. Propensity to pay and amount to pay in the whole sample.

	Air pollution	Noise	Total
% Pay	40%	29%	<b>34.50%</b>
Mean	€ 10.28	€ 7.44	<b>€ 17.72</b>

Table 8.12. Propensity to pay and amount to pay removing zero protest

	Air pollution	Noise	Total
% Pay	45%	33%	<b>39%</b>
Mean	€ 11.72	€ 8.46	<b>€ 20.18</b>

As final results, we can say that 34.50% of people value somehow road transportation externalities in € 17.72. When removing zero protest, those amounts increase to 39% and € 20.18 respectively. These results are consistent with those obtained in other studies such as Alberini and Chiabai (2007), O'Garra et al (2007), Palatnik et al. (2005), Wang and Mullahy (2006), Torgler and Garcia-Valiñas (2009) and Bjørner (2004) as well as with Lera-López et al. (2014b).

## 4. Conclusions

Noise and air pollution by road transportation are some clear social and public problems in rural and urban areas. Moreover, this work is focused on the two main roads crossing the Pyrenees between Spain and France. Thus, we carried out an economic assessment of these two types of environmental problems. As an additional feature, we took into account the zero responses which represent an attitude of protest. As it has been seen throughout the entire work, the WTP implies two decisions: firstly, whether to pay or not and, secondly, the amount to pay. Methodologically speaking, all models produce very similar results, detecting the two-phase nature of this decision.

In general the same factors which influence the first phase do again in the second one but with different intensities.

Finally, this study can draw a number of more specific conclusions and that shed light on the question of WTP to reduce the harmful effects on the environment of road transportation and could be considered as recommendations. These are the next ones:

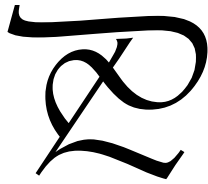
- Younger respondents with higher education show higher values of WTP.
- We could reduce environmental problems by improving the educational level of the population.
- Zero protest analysis has led us to know that the protest attitude is easier to find in the Basque Country.
- Environmental concern is determinant in the WTP in all cases. Therefore, policies based on increasing social and individual concern will impact positively on the WTP to reduce noise and air pollution.
- People who cause noise and air pollution should pay some environmental taxes. Consequently, the 'Eurovignette' policy is an inevitable consequence of the widespread use of road transport in Europe. New taxes associated to greener transport are expected in the long run.
- Logically, the WTP is higher in areas with greater environmental value (such as the Pyrenees). However, these areas could enjoy special protection since no payment policy can compensate the caused damage.





## CHAPTER 9.

# PRICING AND INTERNALIZING NOISE EXTERNALITIES IN ROAD FREIGHT TRANSPORTATION



*People living close to main roads may suffer from the nuisance of traffic and noise pollution. This chapter assesses the effect of full routing cost in vehicle routing decisions by internalizing the external cost of noise. On a first step, noise externalities are economically assessed through a contingent valuation procedure. Secondly, a novel methodology is proposed to allocate the external costs to the road network links. Results show significant differences in routing planning depending on the approach: minimization of traditional internal cost versus minimization of full cost. These results encourage further research in pricing and methodologies to internalize externalities.*

This chapter is based in the following research contribution:

Serrano-Hernandez, A., Alvarez, P., Lerga, I., Reyes-Rubiano, L., and Faulin, J. (2017). Pricing and Internalizing Noise Externalities in Road Freight Transportation. *Transportation Research Procedia*, 27: 325-332.

## 1. Introduction

According to the [European Commission \(2016\)](#), half of all goods in Europe are moved using road transportation, being the responsible of 5% of the European GDP and employing about 3 million people. Furthermore, road freight transportation accounts for 24% of all greenhouse gases emitted in the European Union which contributed to global warming and it is also source of stress, sleep disturbance and other noise-related issues. Therefore, research on road transportation economic, social, and environmental impacts is of utmost interest.

Transport planning has long been focused on its economic aspects. Traditionally, researchers have paid great attention to route optimization in order to get the cheapest way to fulfill a transport activity without considering environmental impacts. However, negative externalities of road freight transportation related to air pollution and excessive noise levels are particularly perceptible. In this context, different green transportation concepts aiming to reduce these impacts have recently been presented ([Kadziński et al. 2017](#); [Muñoz-Villamizar et al. 2017](#); [Toro et al. 2017](#)). Most optimization models consider emission estimations which are based on routing characteristics such as distance, load levels, vehicle type, or road gradient, and which ultimately depends on fuel consumption. These estimations are then included in the objective function in order to minimize the relevant variable.

By either focusing on monetary or environmental goals, different factors are considered as decision variables. Thus, in order to efficiently account for internal and external routing costs, new pricing models are necessary to incorporate external costs on corporate decision-making processes ([Demir et al. 2015](#)). One possibility to evaluate non-market goods, i.e. air pollution, noise, etc., is through the contingent valuation method (CVM) ([Istamto et al. 2014](#)). The CVM is based on stated preference surveys in which a population sample is asked for their willingness-to-pay (WTP) to achieve a hypothetical scenario with a greater level of utility. That is, through the CVM a hypothetical market is created for a good that could be bought by customers. The obtained value refers to the difference in the welfare of the individual by passing from the current scenario to the new one.

The literature presents a wide range of different emission models which typically replace 'traditional' optimization objectives related to costs reduction. In this work, we want to go one step beyond these approaches by internalizing negative externalities. Firstly, external cost from noise pollution is estimated through stated preference surveys. Secondly, a methodology based on source-receptor relationship is proposed to allocate the external costs to the links. Finally, several instances were generated within the case-study region allowing us to identify transport management insights.

## 2. Related literature

An externality refers to a situation in which the costs or benefits of production and/or consumption of a good or service are not reflected in its market price (Pigou, 1920). In other words, externalities are those activities that affect others without paying for them or being compensated. According to Ranaiefar and Regan (2011), negative routing externalities can be classified into four different impact areas: the (i) economy, which includes congestion, road damage and longer travel times; (ii) society, comprising accidents, intrusion and noise pollution; (iii) ecology, encompassing biodiversity destruction and climate change; and (iv) the environment, including waste, air, and water pollution. Many research works have tried to physically measure such externalities. To this respect, Demir et al. (2015) gave an extensive review on externalities modeling in which they accounted for several different methodologies to deal with noise and air pollution, congestion and accidents. The same paper also includes a pricing section, concluding that further research should be made in that direction.

In order to internalize such externalities in delivery route planning, monetary values have to be considered in order to be able to price these factors. Therefore, a large-scale survey, applying the CVM, was conducted in the case-study area. This methodology was adopted by authors such as Lera-López et al. (2014a) or Lera-López (2012) in a Spanish region to study air and noise pollution obtaining WTP values around €8 per externality, household, and year. In extremely polluted areas, such as Shanghai in China, the value rises to nearly €65 in the similar hypothetical scenario of air quality improvement (Wang et al. 2015).

Physical measure of noise pollution (mainly in decibels) is complex as it takes into account many factors such as surface, tire typology, or meteorology (Kephelopoulos et al., 2012). The consideration of non-traditional factors is more frequent in the case of air pollution, where the Green Vehicle Routing Problem (GVRP) has become a recurrent topic. Since emissions and fuel consumption are related, most of the GVRP research has focused on the minimization of fuel consumption through optimizing a relevant variable (i.e. load, speed, road gradient...) as discussed by Demir et al. (2014) and Lin et al. (2014). An approximation is given by Bektaş and Laporte (2011) where the pollution routing problem is defined. The authors concluded that the minimization of emissions does not result in the minimization of costs, whereas emission costs are quite insignificant in comparison to fuel and driver costs. It is remarkable that those emissions costs are simply computed by a cost figure provided by DEFRA (2007) who estimated the value of a ton of CO<sub>2</sub> in GBP 27 (2002). Fuel consumption is then translated into CO<sub>2</sub> emissions at a rate of 2.32 kg of CO<sub>2</sub> per liter as suggested by Coe (2005). In this last paper there is no evidence of internalization. Zhang et al. (2015) later discussed a similar problem in which internalization of emissions cost was carried out through a similar unit emissions cost value based on fuel consumption. In that case, the cost emission per liter of fuel consumption was set to CNY 0.64,

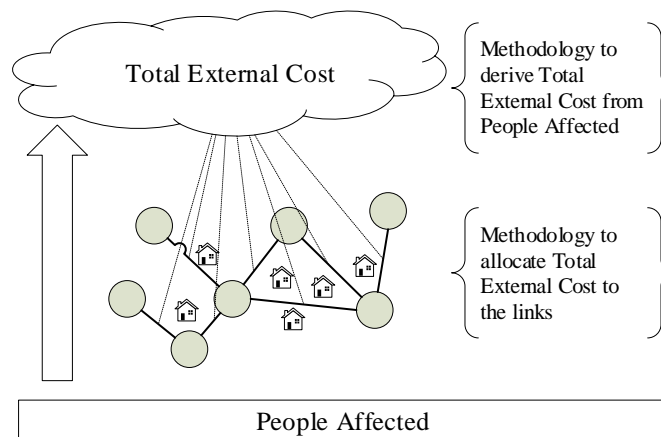
while no information about that figure was provided. Finally, a recent example is presented by [Eshtehadi et al. \(2017\)](#) in which the relationship between fuel consumption and speed is illustrated. According to the authors, there exists inefficiency in the use of fuel at low speeds resulting in higher consumption. Later, a decrease of consumption occur until some point (60-65 km/h) when fuel consumption increases again as a result of aerodynamic drag. Then the fuel consumption may be scaled by the payload.

Certainly, scientific literature has focused on two approaches without mixing. On the one hand, literature about emission measurement, i.e. CO<sub>2</sub>, where the physic measure is implemented into optimization problems with the goal of obtaining the least polluted solution. On the other hand, literature focused on the economic quantification of some range of externalities but without further implication in logistics activities. Therefore, there is a gap where very few papers have tried to bring some light because either a simplistic vision or an incomplete implementation.

### 3. Methodology

The methodology consists of two steps as described in Figure 9.1: (i) deriving the total external cost and (ii) allocating it to the links. Afterwards, when the vehicle passes through the link these external costs can be added to the internal ones forming the full cost. Finally, the full cost is considered in the route planning process.

Figure 9.1. Methodology overview



#### 3.1. Total External Costs

The total external cost is the economic valuation of the externality under consideration within a reasonable time period in a given region. To this respect, it is assumed that WTP values given by

the population are a good approximation of the economic value of the externality since it takes into account the socioeconomic characteristics and their real affliction of the externalities (economic quantification of the loss of welfare). Thus, the total external cost can be computed as the summation of all WTP values obtained. Once the total external cost is estimated, an approach to allocate it is necessary as next subsection describes.

### 3.2. Costs Allocation Model

The cost allocation model is partially inspired by the Impact Pathway Approach (European Commission, 2003) in which transport externalities are mainly generated by heavy commercial vehicles (the source) and assumed by the affected people (the recipients). Thus, allocation is made to links depending on the number of households affected and the intensity of heavy traffic. Therefore, the external cost associated to the link  $i$  is computed according to Equation (9.1):

$$\varepsilon_i = \frac{T_i H_i}{\sum_i T_i H_i} E \quad (9.1)$$

Where  $T_i$  is the average flow of heavy vehicles passing through link  $i$ ,  $H_i$  are the households affected in that specific link, and  $E$  is the total external cost, with  $\sum \varepsilon_i = E$ .

## 4. Case Study

A case study has been developed to test the proposed methodology in the Spanish region of Catalonia. This region is particularly important in road freight transportation as it is one of the two major connections of the Iberian Peninsula to the rest of Europe. Actually, according to the Spanish-French Observatory of Road Transport at the Pyrenees (2017) more than 30,000 vehicles use the Mediterranean route daily, being 10,000 of them heavy ones.

### 4.1. Total external costs and parameter setting

A contingent valuation survey was conducted in the case study region. To estimate the WTP for reducing traffic-related noise externalities, the population was chosen among inhabitants of Catalonia in Northeast Spain. The region has a population of 7.5 million people where a total of 800 households were surveyed through phone interviews. The questionnaire, which was carried out in December 2012, consisted of 3 sections, as suggested by Mitchell and Carson (1989): (i) introduction, where the problem is described; (ii) contingent valuation that contains open-ended questions used to obtain WTP; and (iii) classifying questions aiming to obtaining further information from respondents (age, gender, income, and environmental concerns). The survey

results state that an average household is willing to pay €8.52 in order to reduce its noise nuisance. Moreover, a total of 223,280 households are sited within 200 meters along major road. That results in a total external cost for noise of €1,902,347.

#### *4.2. Solution procedure*

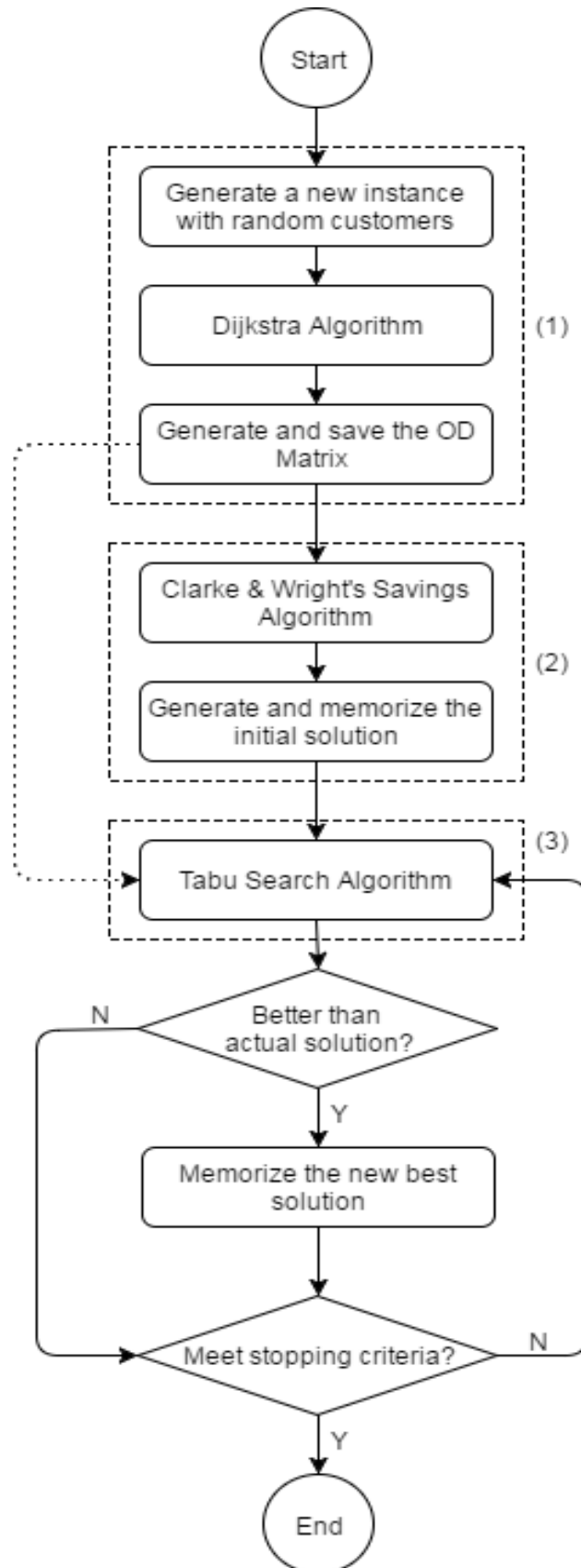
The proposed method has been implemented as a Java application, mainly because it allows a rapid, platform-independent development of algorithms that can be used to test our approach.

Our procedure consists of three phases as shown in Figure 9.2:

- First phase (1). The process starts with the generation of a new random instance of customers within the road network of Catalonia. Then, the Dijkstra Algorithm generates the OD matrix (minimum distances) between the depot and all the customers and saves it into an external file.
- Second phase (2): Making use of the file generated, the best solution that CWS heuristic is able to achieve is saved in order to be implemented as an initial solution in the Tabu Search.
- Third phase (3): Improvement of the solution through a Tabu Search. That metaheuristic guides the local search heuristic algorithm to explore the space of solutions beyond local optima. To do so, a flexible memory is implemented, where some previous movements are saved to avoid them during a number of iterations. Its operating core is the following:
  - Selection of an initial solution (in our case the CWS solution).
  - Choice of the environment and generation of a new solution.
  - Evaluation of the objective function.
  - Update of the best solution.
  - Stopping Criteria.

In our case, the Tabu list size has been set equal to the number of customers because of its better performance, and the number of iterations is 100,000 in order to get the solution without a high computational load in a few seconds.

Figure 9.2. Solution procedure



## 5. Results

A real road network in Catalonia, Spain, was used to test the proposed methodology. It consists of more than 330 links and 310 nodes. Different cases of minimizing Internal Cost (IC), External Cost (EC) and Full Cost (FC) were set as the objective function for the Vehicle Routing Problem (VRP). Note that the IC corresponds to the traditional distance-based VRP in which a cost parameter of 1.15 €/km has been applied. This value is appropriate for an average articulated truck operating in Spain (Spanish Ministry of Transportation, 2016). The EC refers to the cost assigned to links through Equation (7.1) whereas FC is the summation of IC and EC.

A total of 10 customers and 1 depot were randomly assigned to the nodes and 5 instances were created in which the initial proposed WTP value varied from €8.52 to 3 times higher. A Visual Basic program was developed to create 30 runs per instance in order to take stochasticity effects into account. Results indicate that similar results are obtained when increasing the number of customers, although these are not reported due to space limitations. Moreover, truck capacity was set to 50 and customer demands were randomly assigned from 1 unit to  $\frac{1}{4}$  of the truck capacity. Before each run, customers are randomly reassigned to the nodes, then our solution procedure is applied with the three proposed objectives, i.e. min IC, min EC and min FC. Preliminary results are shown in Table 9.1, where values correspond to the average for the 30 runs.

Table 9.1. Numerical results corresponding to Min IC, EC and FC

	Min IC			Min EC			Min FC		
	IC	EC	FC	IC	EC	FC	IC	EC	FC
WTP x 1	699	154	854	1035	124	1160	713	137	850
WTP x 1.5	699	232	931	1050	187	1237	718	214	933
WTP x 2	699	311	1025	1070	240	1311	715	288	1003
WTP x 2.5	699	389	1103	1090	301	1391	704	361	1065
WTP x 3	699	472	1198	1084	358	1443	709	425	1134

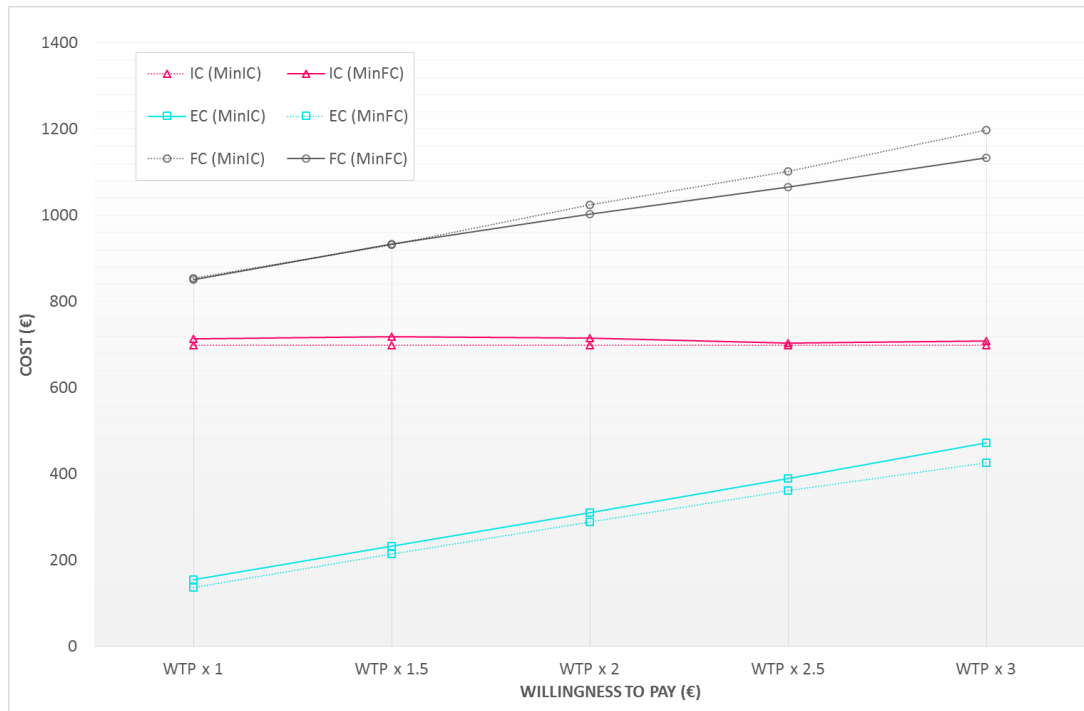
According to Table 9.1, internalization of external costs would increase total costs by 21-22% (FC/IC), having further implication in the routing design. Focusing on the base scenario (WTPx1), Min IC and Min EC show extreme solutions, being Min FC the intermediate one. When minimizing full cost (Min FC) instead of internal costs (Min IC), the IC raises by 2% whilst the EC drops by 11%. This leads to a more profitable FC (difference with Min IC is -0.5%) which highly improves (-5%) in a hypothetical scenario of WTPx3. The ratio EC/FC is also improved when full cost is minimized instead of internal cost (16% and 18% respectively), although the best ratio is obtained when we minimize the external cost (10%). The values obtained are in line



with those from the literature (Márquez and Cantillo, 2013). The results show that even in the WTPx1 scenario, our approach of optimizing the full cost leads to more efficient solutions.

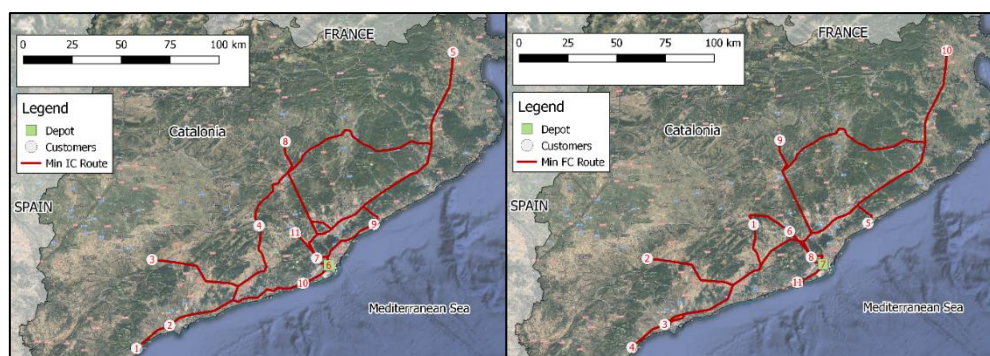
The effect of increasing the value of the externality (WTP) is better described in Figure 9.3. On the one hand, FC and EC show an increasing tendency as the WTP values go up. On the other hand, the greater the WTP values are, the higher the difference is between the FC when FC is minimized and when IC is minimized.

Figure 9.3. Results comparison varying initial WTP up to 3 times higher



In this case-study, the internalization of the external cost caused by noise would lead to a significant change in the routing planning. An illustrative outcome is described in Figure 9.4. Numbers in circles represent the order customers are being visited. In this scenario the truck has to return to the depot once. Routes vary depending on the variable being minimized: internal cost (left) or full cost (right). Note that routes obtained when the full cost is minimized (i.e. when the externalities are being considered) avoid passing through high-density areas such as Barcelona or other coastal areas. As seen in Table 1, the avoidance of certain links needed to take noise into consideration increases the internal cost, although the full cost is minimized.

Figure 9.4. Changes in routing planning minimizing IC (left) and minimizing FC (right)



## 6. Conclusions

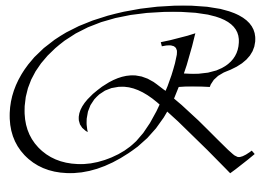
Profit and loss accounts of transportation firms contemplate costs related to operational activities such as purchases of raw materials, salaries of employees, or depreciation, among others. Nevertheless, costs in environmental/social terms are not included in their conventional balance reports and, therefore, they are beyond their control. By definition, externalities are outside the market mechanisms, i.e. they are not reflected in prices. Thus, externalities are not always considered by transport companies which leads to inefficiencies in the market and to the environment and social detriment. Significant externalities arise from road transportation that should be added to the traditional internal cost in order to achieve a full cost that is fair. By internalizing external costs, transport companies will take into account such effects in their decision making processes and so they would be measured, controlled and optimized. Moreover, research on transportation externalities is of highest interest as cities and regions are becoming more sustainable. From a social point of view, noise pollution emitted from traffic may increase the risk of heart disease, hearing loss, stress, or sleep disturbances. This work addresses the topic of internalizing the external cost of noise. For this purpose, a contingent valuation survey was conducted in Catalonia, Spain, to derive the external cost of noise. A novel methodology is later implemented to allocate the total external cost caused by noise to every link in the road network.

Results suggest that transport decisions (for example, routing planning) would significantly change if internalization were performed. First, accounting for external costs leads to an increase in costs of about 20%; secondly, a new optimization dimension is presented in which full cost replaces the traditional internal cost optimization. Future research directions involve the internalization of a wider range of externalities such as air pollution, congestion or accidents. Moreover, a more sophisticated methodology would be required to quantify these externalities, as well as for estimating the total external costs. Finally, an effective and realistic tool for internalization would be necessary, for example through taxes or tolls.



## CHAPTER 10.

# INTERNALIZING NEGATIVE EXTERNALITIES IN VEHICLE ROUTING PROBLEMS THROUGH GREEN TAXES AND GREEN TOLLS



*oad freight transportation includes various internal and external costs that need to be accounted for in the construction of efficient routing plans. Typically, the resulting optimization problem is formulated as Vehicle Routing Problem (VRP) in any of its variants.*

*While the traditional focus of the VRP was the minimization of internal routing costs such as travel distance or duration, numerous approaches to include external factors related to environmental routing aspects have been recently discussed in the literature. However, internal and external routing costs are often treated as competing objectives. This chapter discusses the internalization of external routing costs through the consideration of green taxes and green tolls. Numeric experiments with a biased randomization savings algorithm, show benefits of combining internal and external costs in delivery route planning*

This chapter is based in the following research contribution:

Serrano-Hernandez, A., and Faulin, J. Internalizing Negative Externalities in Vehicle Routing Problems through Green Taxes and Green Tolls. *International Journal of Logistics-Research and Applications*, under review.

## 1. Introduction

The Vehicle Routing management is one of the most important operational activities in road freight transportation. Delivery routes are typically established by solving the NP-hard Vehicle Routing Problem (VRP) in any of its variants (Caceres-Cruz et al. 2014; Toth and Vigo, 2014). However, the optimization of explicit operational costs is only one side of the coin.

Delivery route planning has long focused on monetary aspects. Nevertheless, the negative externalities of road freight transportation related to air pollution, excessive noise levels, and traffic congestion are particularly noticeable in urban areas (European Union, 2012; United Nations, 2016; European Commission, 2009). In this context, different green logistics concepts aiming to reduce the negative impacts of road transportation have recently been presented (Bektas and Laporte, 2011; Gajanand and Narendran, 2013; Lin et al. 2014). Typically, some kind of emission estimation based on routing characteristics such as distance, load levels, vehicle type, road gradient, etc. are included in the optimization models. These estimations are then considered in the objective function in order to minimize the relevant variable.

By either focusing on monetary- or environmental objectives, different factors are treated as competing variables, looking for either the cheapest solution or the least polluting option. Therefore, a way to internalize negative externalities into operational costs is of utmost interest. This chapter proposes internalization through green taxes and green tolls, and evaluates the effects on company behaviors of such fiscal policies. Moreover, this chapter reviews relevant literature about monetization of environmental costs and propose those values as taxation.

## 2. Literature review

Within the context of green logistics and road freight transportation, environmentally aware delivery route planning has received much attention in recent years (Helo Ala-Harja, 2018). Next to new optimization problems arising from the use of new technologies such as electric vehicles (Juan et al. 2016) and the development of innovative supply chain strategies such as horizontal collaboration aimed at reducing routing related emissions (Perez-Bernabeu et al. 2015), especially the inclusion of green minimization objectives has been discussed. In this context, the green VRP (GVRP) focuses on minimizing fuel consumption instead of traditional cost- or distance based optimization targets (Erdogan and Miller-Hooks, 2012). The environmental routing impact is typically estimated with respect to the operating vehicle and some distinct criteria effecting predicted consumption/emission values. Especially travel speed, vehicle load levels, routing

distances, and road gradients have been discussed (Bektas and Laporte, 2011; Demir et al., 2014; Lin et al. 2014).

Even though the GVRP is still a rather new topic, some optimization approaches have already been presented (Ubeda et al., 2011). The energy minimizing VRP is defined by Kara et al. (2007), who propose a cost function for the VRP based on the product of vehicle load and travel distance. In Tavares et al. (2009), road gradient and vehicle weight is considered in optimizing fuel consumption in waste collection processes. The time dependent VRP is addressed by Kuo (2010). While the author considers different travel times and varying vehicle speed depending on the time of the day, the objective function is the minimization of fuel emissions considering vehicle loads and travel speed. The resulting model is solved with a simulated annealing metaheuristic, showing significant reductions of fuel consumption compared to objectives based on the minimization of travel time/distance. A fuel consumption rate based on vehicle load levels (similar to the approach applied in this paper) is proposed in the work of Xiao et al. (2010). The potential benefits of applying environmentally driven models compared to traditional VRPs is also shown using a simulated annealing approach. Even though not directly related to the GVRP, the load dependent vehicle routing problem is closer examined by Zachariadis et al. (2015). The authors consider cargo weight variations in routing activities in which transported cargo accounts for a significant amount of vehicle weight. Fuel consumption is, however, not directly addressed in their work.

### 2.1. Routing externalities and internalization

Considering the definition by Laffont (2008), externalities are ‘(...) *indirect effects of consumption or production activity, that is, effects on agents other than the originator of such activity which do not work through the price system*’. Thus, it becomes clear that not only environmental aspects related to emission factors have to be included in routing optimization. According to Ranaiefar and Amelia (2011), negative routing externalities can be classified into four different impact areas: (i) economy, which include congestion, road damage and longer travel times; (ii) society, comprising accidents, visual intrusion and noise pollution; (iii) ecology, encompassing biodiversity destruction and climate change; and (iv) the environment, including waste, air, and water pollution. Many works have tried to physically measure such externalities. To this respect, Demir et al. (2015) give an extensive review on externalities modeling in which they accounted for several different methodologies to deal with emissions, noise, congestion and accidents. The same paper also includes a pricing section, concluding that further research should be made in that direction.

In order to incorporate such externalities in delivery route planning, monetary values have to be considered to be able to price these factors. Different approaches were carried out by Litman

(2009) and Delucchi and McCubbin (2010) reports. In the extensive Litman (2016) one, it is reviewed plenty of prior works regarding transportation costs (internal and external). Noise and air pollution are visited listing various circumstances to estimate the external cost. For instance, noise costs depend on the type of vehicle, density of the area, type of road and daytime. According to their revision, the 34 tonne-truck noise costs range from 2007 USD cents 0.0088 to 2007 USD cents 0.235294 per tonne and mile whereas the Delucchi and McCubbin (2010) one estimates in 2006 USD cents 0.0-5.3. On the other hand, air pollution cost is usually analyzed from the "damage function" approach described by Adamowicz (2003). It consists of valuating the relationship in welfare due to a change in the emissions, mainly divided into different types of harmful emissions: CO<sub>2</sub>, CO, PM<sub>10</sub>, CH<sub>4</sub>, and so on. Later, a price is assigned to each based on health care costs. Then, physical emissions are calculated and translated into monetary units using the previous prices. In the report, Litman (2016) concluded the automobile air pollution costs range from 2007 USD cents 0.0032 to 0.7352 per tonne and mile similarly to Delucchi and McCubbin (2010) who estimate such costs in n 2006 USD cents 0.1-18.7. Note that the high variation is due to the different characteristics in the vehicle, road and weather conditions, being so one of the main drawbacks.

Regarding internalization in logistics activities, it is noticeable the Abdallah et al. (2012) work who presented a novel approach to greening the supply chain. They took into account a carbon trading mechanism for pricing emissions. Later, they formulated a mixed integer program that minimizes the sum of supply chain costs and carbon trading costs.

### 3. Internalization of green taxes and green tolls

The capacitated VRP can be formulated on a graph  $G = (V, E)$ . Vertex set  $V = \{L \cup 0\}$  describes a subset  $L = \{1, 2, \dots, l\}$  of  $l$  customer nodes with demand  $d_i \geq 0$  and the central depot 0, at which a homogeneous fleet of vehicles with maximum capacity  $Q$  is located. Set  $E = (i, j): i, j \in V, i \neq j$  describes the connections between any two nodes  $i$  and  $j$ , whereas the travel distance  $d_{ij}$  to traverse any edge are assumed to be known. The objective of the (traditional) VRP is to find a establish a distance minimizing route to serve all customer demand, subject to the following constraints: (i) vehicle routes start and end at the same depot, (ii) no customer node is visited twice, and (iii) vehicle capacities need to be adhered to.

Naturally, the objective of minimizing overall travel distance can be enhanced. Our approach introduces external costs  $ec_{ij}$  for each edge  $(i, j) \in E$  that are made of green taxes  $t_{ij}$  and green tolls  $v_{ij}$ . Therefore, the full cost  $fc_{ij}$  associated to each edge is described in Equation (10.1):



$$fc_{ij} = ic_{ij} + ec_{ij} = ic_{ij} + t_{ij} + v_{ij} \quad (10.1)$$

The green taxes are charged on fuels so they will depend on fuel consumption whereas green toll costs are charged as tolls if the vehicle enters in high quality environmental areas that may be somehow protected. Note that now we deal with a directed graph since  $fc_{ij}$  may not be equal to  $fc_{ji}$ . Real example of a green toll is working though some European countries. Known as Eurovignette (European Union, 1999), it is a road user charge for heavy vehicles to account for external costs of air and noise pollution, among other costs. Therefore, the objective function consists of two components: the traditional distance-based (internal) costs and the external costs, compounded by the green taxes and the green tolls:

- *Internal costs.* These costs comprise driver wage, asset depreciation and fuel cost and can be summarized as showed in Equation (10.2) where  $C_d$  is a cost parameter per unit of distance for any edge.

$$ic_{ij} = C_d d_{ij} \quad (10.2)$$

- *External costs.* Green tax costs are charged to fuel. Therefore, the amount of Green Tax paid is described in Equation (10.3), where  $C_t$  is a cost parameter per unit of fuel consumed  $\varphi_{ij}$ . On the other hand, the green toll is paid according to the environmental category of the area as described in Equation (10.4).

$$t_{ij} = C_t \varphi_{ij} \quad (10.3)$$

$$v_{ij} = \begin{cases} C_v^l, & \text{if node } j \text{ belongs to a low environmental value area and node } i \text{ does not} \\ C_v^m, & \text{if node } j \text{ belongs to a medium environmental value area and node } i \text{ does not} \\ C_v^h, & \text{if node } j \text{ belongs to a high environmental value area and node } i \text{ does not} \\ 0, & \text{otherwise} \end{cases} \quad (10.4)$$

### 3.1. Measuring fuel consumption

Estimating properly the fuel consumption is of utmost interest in our work since most of pollutant are released to the environment when fuel is burnt. Thus, we have used to this purpose, the methodology proposed in Knör and Kutzner, (2016) since it is updated and well documented, and it takes into account upstream energy consumption (generation and distribution of energy), also known as well to tank (WTT).

In such methodology, energy consumption is measured in megajoules and it depends on distance, payload, road slope, speed, and vehicle characteristics. All in all, for any given distance, the fuel consumption  $\varphi$  can be represented as a function of load weight as showed in Equation

(10.5) where  $\varphi_e$  is the fuel consumption when empty,  $\varphi_f$  is the fuel consumption when full loaded,  $P$  is the payload and  $Q$  is the vehicle capacity.

$$\varphi = \varphi_e + \frac{(\varphi_f - \varphi_e)P}{Q} \quad (10.5)$$

### 3.2. Pricing air pollution and GHG emissions- estimating $C_t$

Air pollution is caused by emission of air pollutants like NO<sub>x</sub>, SO<sub>2</sub>, non-methane volatile organic compounds (NMVOC), and particulate matters (PM) that affect people, vegetation, materials and global climate. Climate change or global warming impacts of road transport are, mainly, generated by emissions of greenhouse gases (GHG): carbon dioxide (CO<sub>2</sub>), nitrous oxide (N<sub>2</sub>O) and methane (CH<sub>4</sub>). Nevertheless, CO<sub>2</sub> is the dominant anthropogenic GHG, and the remaining GHG can be expressed as CO<sub>2</sub> equivalent (CO<sub>2</sub>e) as described in Equation (10.6):

$$CO_2e = CO_2 + 25CH_4 + 298N_2O \quad (10.6)$$

Table 10.1, based on Korzhenevych et al., (2014) shows average EU prices for 1 kg of pollutant component, in €(2010). On the one hand, air pollution components are priced, generally, attending to the related health costs and crop losses. Later they are computed based on the average exposure. On the other hand, GHG, i.e CO<sub>2</sub>e, are priced attending to prevention costs to reduce risk of climate change and the damage costs of increasing global temperature.

Table 10.1. Prices for 1 kg of emitted component in €(2010), based on Korzhenevych et al., (2014)

Component	Harmful effects	€(2010)/Kg
NO <sub>x</sub>	Smog, soil acidification	12.81
NMVOC	Smog, damage to health	1.89
SO <sub>2</sub>	Soil acidification, damage to health	12.35
PM	Damage to health	47.73
CO <sub>2</sub> e	Climate change	0.11

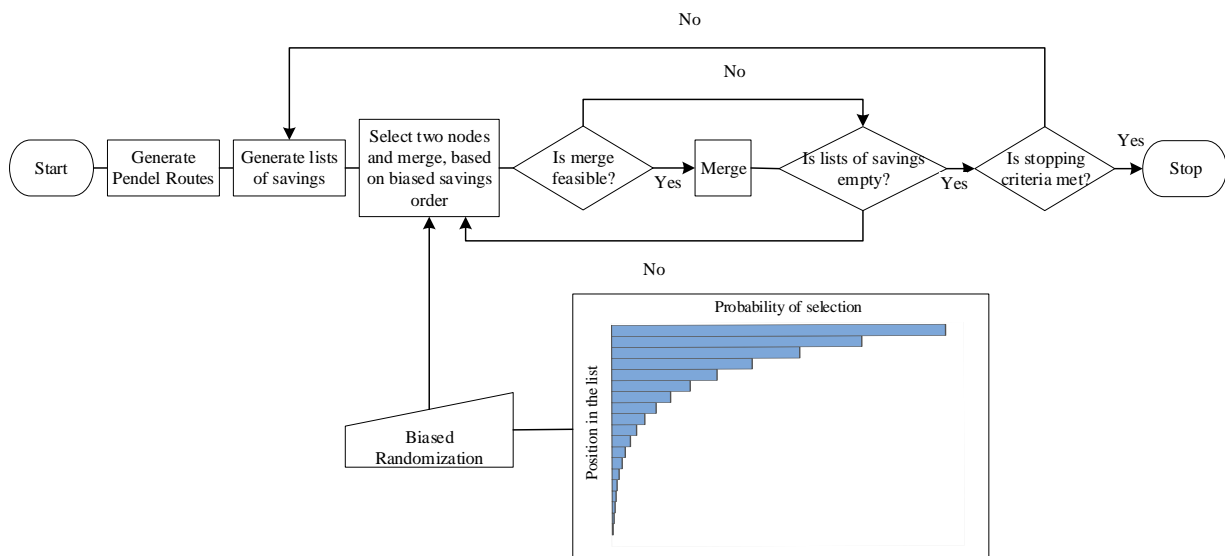
## 4. Solving approach

The Vehicle Routing Problem (VRP) is one of the most studied problems in combinatorial optimization, with many real-world applications as well as logistics and transportation (Toth and Vigo, 2014). Since its appearance in 1959 by Dantzig and Ramser (1959), who made for the first time a formulation of the problem for a fuel distribution application, the study of the VRP problem has generated numerous research works and thousands of articles have been written about many

variants of the classical problem (Caceres et al. 2015). VRP is known to be a NP-hard problem and its exact solution can be only achieved for very small instances. Therefore, heuristics algorithms are widely used for solving the VRP. To this respect, savings heuristic proposed by Clarke and Wright (1964) is still widely used because it is simple to implement and it returns good and extremely fast solutions. Nevertheless, many improvements can be made to this classical heuristics in order to obtain better solutions.

A biased randomization of the classical savings heuristics is proposed in this chapter following the ideas described in Grasas et al. (2017) and Juan et al. (2015) who showed the competitiveness of the proposed algorithm. This randomization is performed in the constructive phase using a probability distribution for selecting the nodes to merge. By doing so, every time the heuristic is executed, a different solution is returned that may outperforms the best solution obtained so far. Therefore, the main difference of the randomize version of the savings heuristics is that it does not always pick the first position in the savings lists. Moreover, the ‘biased’ adjective is added in such a way that the probability of selecting the nodes is not uniformly distributed but biased, contrarily to greedy proposals. In our case, we used the geometric distribution as skewed probability distribution and savings are computed using costs definitions presented in the previous sections. The parameter describing the considered distribution function is initially set at 0.2 but it is implemented a learning mechanism within the algorithm framework. This mechanism consists of continuously updating the aforementioned parameter based on the solution reported in the previous iteration in such a way that if a solution obtained is at least 5% worse that the best obtained so far, parameter is changed for the next iteration in the same proportion in both up and down directions. The Figure 10.1 shows the flowchart of the proposed algorithm.

Figure 10.1. Biased-randomized savings algorithm



## 5. Experimental results

### 5.1. Parameter setting

Augerat et al. (1995) set A instances are used as database because its wide implementation in which coordinates are random points in a [100, 100] grid and demands are generated from an uniform distribution  $U(1,30)$  (Uchoa et al. 2017; Faulin et al., 2011). Vehicles are defined as a standard EURO V 26-40 truck, i.e.  $Q=26$  and curb weight = 14; for parameter setting, based on Ecotransit estimations Knorr and Kutzner (2016). Since upstream energy consumption is taken into account, conversion factors referring to WTW are used as shown in Table 10.2. A standard desktop with an Intel® Core™ i5- 3570 CPU @ 3.40 GHz and 8GB RAM was used to run all the experiments in with a time limit was set at 120 seconds.

Table 10.2. Conversion factors for tank to wheel (TTW) and considering upstream energy consumption- well to wheel (WTW), based on Knörr and Kutzner (2016).

	TTW	WTW
MJ/l diesel	35.86	42.68
gr NOx/l diesel	6.79	8.25
gr NMVCO/l diesel	0.12	0.93
gr SO <sub>2</sub> /l diesel	0.01	1.08
gr PM/l diesel	0.11	0.16
kg CO <sub>2e</sub> /l diesel	2.67	3.24

With the following Equation (10.7) estimated diesel fuel (liters) consumption function based on payload and distance, where parameters  $\varphi_e$  and  $\varphi_f$  have been replaced by their real values according to the aforementioned vehicle.

$$\varphi = \left(0.2364 + \frac{0.15P}{26}\right); \quad 0 \leq P \leq 26 \quad (10.7)$$

The green tax is set through the economic valuation of air pollution and GHG described in the Table 10.1 of Section 3. The computation is showed in the Table 10.3.

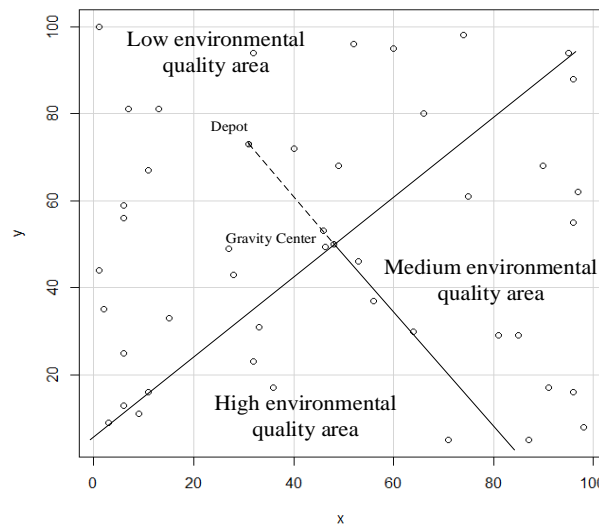
Table 10.3. Details of computation of parameter  $C_t$

Pollutant	kg emitted per liter	Price per kg	Total
NOx	0.00825	12.61	0.1040
NMVCO	0.00093	1.73	0.0016
SO <sub>2</sub>	0.00108	12.03	0.0129
PM	0.00016	47.43	0.0075
CO <sub>2e</sub>	3.24000	0.11	0.3564
<b>Total (<math>C_t</math>)</b>			<b>0.4827</b>

With respect to the cost parameter related to the internal costs, ( $C_d$ ), it corresponds to the traditional distance-based VRP in which a cost parameter of 1.15 €/km has been applied. This value is considered appropriate for an average articulated truck that operates in Spain (Spanish Ministry of Transportation, 2016).

Green tolls are set at 0, 10 and 30 for  $C_v^l$ ,  $C_v^m$ , and  $C_v^h$  respectively. We consider those values appropriate in order to significantly influence driver behaviors. Nevertheless they are in line to those proposed in the EU for the Eurovignette (European Union, 1999). Moreover, for our experiments, the nodes have to be assigned to one of the proposed environmental area: low, medium, and high. That process is executed for all instances in such a way that it guarantees that (i) the depot is always in the low environmental quality area, (ii) low environmental quality area represents 50% of the total area, (iii) medium environmental quality area represents 25% of the total area and, (iv) high environmental quality area represents 25% of the total area. The detailed description of the process is as follows. Firstly, center of gravity is computed with all the customers. Secondly, the perpendicular line at center of gravity resulting from linking the depot to the center of gravity is set as the border for the low environmental quality area that the depot belongs to. Thirdly, the other region is also divided into two subregions, following the line from linking the depot to the center of gravity. Finally, the region with fewer customers is set as high environmental quality area and the other is set as medium environmental quality area. If there is a tie in customers, areas are randomly assigned. As an illustrative example, the Figure 10.2 shows the area allocation corresponding to the instance A-n45-k6.

Figure 10.2. Area allocation corresponding to the instance A-n45-k6



## 5.2. Results

Detailed results are depicted in the Table 10.4 to Table 10.7 considering the implementation of the green taxes (Table 10.4), green tolls (Table 10.5 and Table 10.6) and both at the same time (Table 10.7). The structure of the instances is A-nX-kY where X is the number of nodes and Y is the number of vehicles available, i.e. maximum routes (Augerat et al., 1995).

All tables have same structure. The first block contains the values corresponding to the traditional approach, i.e. the objective function is minimizing the internal costs (IC). Information about external costs (EC) was also saved when solving and it is showed in that approach. Finally, FC accounts for the full costs of operation; that is, including internal and external costs. The second block corresponds to the approach in which EC are included; that is, objective function is minimizing the FC. Finally, a difference block is reported to compare the approaches.

Table 10.4 details the results when EC are included as green taxes. On average, including green taxes would lead to a reduction of 26.34% of external costs paid. That fact is achieved by increasing 1.57% the internal costs invoice. All in all, a reduction of 1.62% in FC is reached. Reasons behind such a reduction have to do with a much better utilization of vehicle load as well as a smarter way to do the deliveries. This is achieved by delivering high loads sooner in order to drive higher distances with a lighter vehicle. Particularly interesting is the case of instance A-n54-k7 where a huge reduction in EC is achieved by slightly increasing the IC. That suggest that in some cases there exist strong possibilities of reducing EC with simply taking them into account when optimizing. In general, those opportunities arise in bigger instances.

Table 10.5 depicts the results when implementing EC as green tolls. In that case a reduction of 14.38% in EC can be achieved, again slightly increasing the IC. Nevertheless the effect on FC is lower than in the case of green taxes. Highly interesting is the information referred in the Table 10.6 in which ‘H’, ‘M’, ‘L’ state for the fuel consumed on the areas of high, medium and low environmental quality. A last column (‘T’) is the total fuel consumption within the three areas. Those results suggest the application of green tolls would lead to a reduction in the fuel consumed, i.e. emissions, in the high environmental quality area and an increase in the other two areas. On average, it is obtained a fuel consumption reduction of 2.84% in the high quality area and 0.37% in the medium quality area against an increase of 17.99% in the low environmental quality area. However, that also means that an increase in the fuel consumption is requested. Note that the behavior of the medium quality area is irregular and it is not guaranteed a reduction in fuel consumption in that area as a consequence of implementing green tolls.

Finally, Table 10.7 combines the result of applying green taxes and green tolls as EC. As can be observed, an increase in IC of 1.23% is borne for reducing a 17.56% and a 7.52% the green taxes and green tolls costs, respectively. This finally led to a reduction of 1.49% in the FC. Note that those figures are intermediate values to the one obtained when individually implemented the green taxes and the tolls. However the effect on FC is not so penalized and a reduction on fuel consumption (i.e. emissions) is obtained, contrarily to the implementation of just green tolls. At the same time, given the reduction of the green tolls, it is also gained a redistribution of fuel consumption from the highest environmental quality area to poorer ones.

Table 10.4. Detailed results when implemented green taxes

Instance	Traditional Approach			Green Taxes			Dif IC	Dif EC	Dif FC
	IC	EC	FC	IC	EC	FC			
A-n32-k5	905.05	118.77	1023.82	924.70	95.90	1020.60	2.17%	-19.26%	-0.31%
A-n33-k5	761.30	96.08	857.38	779.50	72.29	851.79	2.39%	-24.75%	-0.65%
A-n33-k6	853.30	109.11	962.41	872.25	87.24	959.49	2.22%	-20.05%	-0.30%
A-n34-k5	898.15	115.87	1014.02	916.36	87.64	1004.00	2.03%	-24.36%	-0.99%
A-n36-k5	922.30	120.21	1042.51	940.86	83.29	1024.16	2.01%	-30.71%	-1.76%
A-n37-k5	772.80	95.59	868.39	787.47	68.16	855.63	1.90%	-28.70%	-1.47%
A-n37-k6	1092.50	140.49	1232.99	1116.90	90.98	1207.89	2.23%	-35.24%	-2.04%
A-n38-k5	841.80	110.08	951.88	861.33	72.25	933.58	2.32%	-34.36%	-1.92%
A-n39-k5	955.65	122.63	1078.28	973.35	89.56	1062.91	1.85%	-26.97%	-1.43%
A-n39-k6	957.95	126.49	1084.44	970.61	94.75	1065.36	1.32%	-25.09%	-1.76%
A-n44-k7	1089.05	141.94	1230.99	1104.89	94.54	1199.43	1.45%	-33.40%	-2.56%
A-n45-k6	1097.10	140.97	1238.07	1114.84	105.63	1220.48	1.62%	-25.07%	-1.42%
A-n45-k7	1320.20	169.46	1489.66	1338.24	137.21	1475.45	1.37%	-19.03%	-0.95%
A-n46-k7	1054.55	137.60	1192.15	1069.46	91.78	1161.25	1.41%	-33.29%	-2.59%
A-n48-k7	1290.30	162.70	1453.00	1300.66	130.06	1430.72	0.80%	-20.06%	-1.53%
A-n53-k7	1173.00	150.63	1323.63	1185.15	118.21	1303.36	1.04%	-21.52%	-1.53%
A-n54-k7	1346.65	176.70	1523.35	1357.27	118.73	1476.00	0.79%	-32.81%	-3.11%
A-n55-k9	1239.70	159.80	1399.50	1249.74	104.87	1354.61	0.81%	-34.37%	-3.21%
A-n61-k9	1197.15	155.94	1353.09	1210.09	127.24	1337.33	1.08%	-18.40%	-1.16%
A-n65-k9	1373.10	177.67	1550.77	1382.27	143.37	1525.64	0.67%	-19.30%	-1.62%
<b>Average</b>	<b>1057.08</b>	<b>136.44</b>	<b>1193.52</b>	<b>1072.80</b>	<b>100.69</b>	<b>1173.48</b>	<b>1.57%</b>	<b>-26.34%</b>	<b>-1.62%</b>

Table 10.5. Detailed results when implemented green tolls

Instance	Traditional Approach			Green Tolls			Dif IC	Dif EC	Dif FC
	IC	EC	FC	IC	EC	FC			
A-n32-k5	905.05	60.00	965.05	905.05	60.00	965.05	0.00%	0.00%	0.00%
A-n33-k5	761.30	60.00	821.30	761.30	60.00	821.30	0.00%	0.00%	0.00%
A-n33-k6	853.30	70.00	923.30	861.38	60.00	921.38	0.95%	-14.29%	-0.21%
A-n34-k5	898.15	60.00	958.15	898.15	60.00	958.15	0.00%	0.00%	0.00%
A-n36-k5	922.30	60.00	982.30	922.30	60.00	982.30	0.00%	0.00%	0.00%
A-n37-k5	772.80	60.00	832.80	772.80	60.00	832.80	0.00%	0.00%	0.00%
A-n37-k6	1092.50	60.00	1152.50	1092.50	60.00	1152.50	0.00%	0.00%	0.00%
A-n38-k5	841.80	80.00	921.80	857.20	60.00	917.20	1.83%	-25.00%	-0.50%
A-n39-k5	955.65	60.00	1015.65	955.65	60.00	1015.65	0.00%	0.00%	0.00%
A-n39-k6	957.95	80.00	1037.95	959.02	60.00	1019.02	0.11%	-25.00%	-1.82%
A-n44-k7	1089.05	110.00	1199.05	1101.19	80.00	1181.19	1.11%	-27.27%	-1.49%
A-n45-k6	1097.10	90.00	1187.10	1113.83	60.00	1173.83	1.52%	-33.33%	-1.12%
A-n45-k7	1320.20	100.00	1420.20	1333.64	80.00	1413.64	1.02%	-20.00%	-0.46%
A-n46-k7	1054.55	120.00	1174.55	1063.81	90.00	1153.81	0.88%	-25.00%	-1.77%
A-n48-k7	1290.30	100.00	1390.30	1293.42	90.00	1383.42	0.24%	-10.00%	-0.50%
A-n53-k7	1173.00	110.00	1283.00	1185.64	90.00	1275.64	1.08%	-18.18%	-0.57%
A-n54-k7	1346.65	110.00	1456.65	1352.35	90.00	1442.35	0.42%	-18.18%	-0.98%
A-n55-k9	1239.70	140.00	1379.70	1250.93	110.00	1360.93	0.91%	-21.43%	-1.36%
A-n61-k9	1197.15	160.00	1357.15	1210.53	120.00	1330.53	1.12%	-25.00%	-1.96%
A-n65-k9	1373.10	160.00	1533.10	1388.13	120.00	1508.13	1.09%	-25.00%	-1.63%
<b>Average</b>	<b>1057.08</b>	<b>92.50</b>	<b>1149.58</b>	<b>1063.94</b>	<b>76.50</b>	<b>1140.44</b>	<b>0.61%</b>	<b>-14.38%</b>	<b>-0.72%</b>

Table 10.6. Fuel consumption allocation within the three areas when implemented green tolls

Instance	Traditional Approach				Green Tolls				Dif H	Dif M	Dif L	Dif T
	H	M	L	T	H	M	L	T				
A-n32-k5	62.90	71.50	111.72	246.12	62.03	71.48	135.65	269.16	-1.40%	-0.02%	21.43%	9.36%
A-n33-k5	56.23	57.71	85.27	199.20	53.62	56.58	111.61	221.82	-4.63%	-1.95%	30.90%	11.36%
A-n33-k6	22.92	66.18	137.04	226.14	22.13	64.94	166.11	253.18	-3.45%	-1.88%	21.21%	11.96%
A-n34-k5	46.33	60.09	134.26	240.68	45.72	59.05	149.92	254.69	-1.32%	-1.74%	11.67%	5.82%
A-n36-k5	51.59	61.24	137.08	249.91	49.79	60.71	155.80	266.30	-3.49%	-0.86%	13.65%	6.56%
A-n37-k5	55.12	50.60	92.63	198.36	53.94	50.97	108.72	213.63	-2.14%	0.72%	17.36%	7.70%
A-n37-k6	93.24	54.74	143.13	291.12	91.49	55.45	165.07	312.01	-1.88%	1.30%	15.32%	7.18%
A-n38-k5	53.32	59.96	115.24	228.52	52.66	59.84	138.29	250.78	-1.25%	-0.20%	20.00%	9.74%
A-n39-k5	76.84	51.15	126.40	254.39	73.75	50.52	145.14	269.41	-4.01%	-1.23%	14.82%	5.91%
A-n39-k6	78.89	64.09	119.33	262.31	77.16	63.40	137.93	278.49	-2.19%	-1.08%	15.59%	6.17%
A-n44-k7	92.37	79.68	122.20	294.25	88.78	80.65	150.02	319.44	-3.89%	1.22%	22.76%	8.56%
A-n45-k6	82.01	60.87	149.28	292.16	80.65	61.24	174.06	315.94	-1.67%	0.61%	16.60%	8.14%
A-n45-k7	106.29	87.68	157.41	351.37	101.85	88.70	175.05	365.60	-4.17%	1.16%	11.21%	4.05%
A-n46-k7	63.26	74.75	147.76	285.77	60.38	75.02	165.54	300.95	-4.54%	0.36%	12.03%	5.31%
A-n48-k7	127.47	68.63	141.09	337.19	124.75	68.46	180.44	373.64	-2.14%	-0.26%	27.89%	10.81%
A-n53-k7	48.96	99.92	163.28	312.16	47.33	101.87	184.50	333.71	-3.33%	1.96%	13.00%	6.90%
A-n54-k7	113.87	54.26	198.38	366.51	109.53	53.19	240.14	402.86	-3.81%	-1.97%	21.05%	9.92%
A-n55-k9	69.38	97.97	163.68	331.03	68.40	96.31	196.34	361.06	-1.41%	-1.69%	19.96%	9.07%
A-n61-k9	100.69	52.82	169.91	323.43	96.31	52.52	189.42	338.25	-4.35%	-0.57%	11.48%	4.58%



A-n65-k9	89.22	86.45	193.17	368.84	87.70	85.38	235.60	408.68	-1.70%	-1.24%	21.96%	10.80%
<b>Average</b>	<b>74.55</b>	<b>68.01</b>	<b>140.41</b>	<b>282.97</b>	<b>72.40</b>	<b>67.81</b>	<b>165.27</b>	<b>305.48</b>	<b>-2.84%</b>	<b>-0.37%</b>	<b>17.99%</b>	<b>7.95%</b>

Table 10.7. Detailed results when implemented green taxes and green tolls

Instance	Traditional Approach				Green Taxes and Green Tolls							
	IC	Tax	Toll	FC	IC	Tax	Toll	FC	Dif IC	Dif Tax	Dif Toll	Dif FC
A-n32-k5	905.05	118.77	60.00	1083.82	906.72	103.56	60.00	1070.28	0.18%	-12.81%	0.00%	-1.25%
A-n33-k5	761.30	96.08	60.00	917.38	766.91	82.04	60.00	908.95	0.74%	-14.61%	0.00%	-0.92%
A-n33-k6	853.30	109.11	70.00	1032.41	860.07	91.19	70.00	1021.25	0.79%	-16.43%	0.00%	-1.08%
A-n34-k5	898.15	115.87	60.00	1074.02	915.00	91.70	60.00	1066.70	1.88%	-20.86%	0.00%	-0.68%
A-n36-k5	922.30	120.21	60.00	1102.51	934.22	96.10	60.00	1090.32	1.29%	-20.05%	0.00%	-1.11%
A-n37-k5	772.80	95.59	60.00	928.39	781.03	78.49	60.00	919.52	1.06%	-17.89%	0.00%	-0.96%
A-n37-k6	1092.50	140.49	60.00	1292.99	1108.09	115.40	60.00	1283.49	1.43%	-17.86%	0.00%	-0.73%
A-n38-k5	841.80	110.08	80.00	1031.88	853.42	93.54	60.00	1006.96	1.38%	-15.03%	-25.00%	-2.42%
A-n39-k5	955.65	122.63	60.00	1138.28	973.14	97.84	60.00	1130.97	1.83%	-20.22%	0.00%	-0.64%
A-n39-k6	957.95	126.49	80.00	1164.44	960.86	102.88	70.00	1133.75	0.30%	-18.66%	-12.50%	-2.64%
A-n44-k7	1089.05	141.94	110.00	1340.99	1103.08	116.75	90.00	1309.83	1.29%	-17.75%	-18.18%	-2.32%
A-n45-k6	1097.10	140.97	90.00	1328.07	1115.89	113.17	90.00	1319.06	1.71%	-19.72%	0.00%	-0.68%
A-n45-k7	1320.20	169.46	100.00	1589.66	1339.97	133.07	90.00	1563.04	1.50%	-21.47%	-10.00%	-1.67%
A-n46-k7	1054.55	137.60	120.00	1312.15	1064.80	110.98	100.00	1275.78	0.97%	-19.34%	-16.67%	-2.77%
A-n48-k7	1290.30	162.70	100.00	1553.00	1310.75	133.01	100.00	1543.76	1.58%	-18.25%	0.00%	-0.60%
A-n53-k7	1173.00	150.63	110.00	1433.63	1191.74	122.81	100.00	1414.55	1.60%	-18.47%	-9.09%	-1.33%
A-n54-k7	1346.65	176.70	110.00	1633.35	1369.31	146.61	110.00	1625.92	1.68%	-17.03%	0.00%	-0.45%
A-n55-k9	1239.70	159.80	140.00	1539.50	1251.76	137.62	110.00	1499.38	0.97%	-13.88%	-21.43%	-2.61%
A-n61-k9	1197.15	155.94	160.00	1513.09	1209.60	133.47	130.00	1473.07	1.04%	-14.41%	-18.75%	-2.64%
A-n65-k9	1373.10	177.67	160.00	1710.77	1392.19	148.37	130.00	1670.56	1.39%	-16.49%	-18.75%	-2.35%
<b>Average</b>	<b>1057.08</b>	<b>136.44</b>	<b>92.50</b>	<b>1286.02</b>	<b>1070.43</b>	<b>112.43</b>	<b>83.50</b>	<b>1266.36</b>	<b>1.23%</b>	<b>-17.56%</b>	<b>-7.52%</b>	<b>-1.49%</b>

## 6. Conclusions

The consideration of external cost of routing is of utmost interest in nowadays society that is increasingly suffering from air pollution, among other externalities. In this sense, literature about transportation externalities has mainly focused on achieving the *greenest* solution, usually omitting the economic implications of those approaches. However, they are the both sides of the same coin and the treatment of environmental and economic objectives as competing variables would lead to myopic solutions. For that reason, this chapter considers the internalization of external costs within the economic structure of the company. Thus, not only the traditional approach of distance based internal costs of routing is taken into account but also the external costs are used as the objective function: that is, minimization of the full costs. Two protocols of internalizing are further analyzed and discussed: green taxes and green tolls.

The effect of implementing green taxes is doubtless. In one hand, behavior of companies when internalize their external costs through a green taxes significantly changes. That means that they plan a different route in order to minimize their full costs. On the other hand, this change allows for a noticeable reduction on fuel consumption, i.e. emissions.

Green tolls effects are rather limited. Even though it also contributes to a change in the behavior of the companies, it is not achievable a reduction in emissions. Instead, an increase and a redistribution of emissions within different environmental areas are obtained. However, those insights are pretty interesting from the policy maker point of view since it is possible to transfer emissions from cherished environmental areas to a valueless ones. This is particularly applicable to protected areas such as national parks or high value landscapes.

Through combining both mechanism an intermediate point is reached. That is, it is possible to change the delivery planning routes in order to make them greener, in the sense that a reduction of fuel consumption is achieved. Moreover, it is possible to obtain fairer scenarios, in the sense that emissions are transferred from high quality environmental areas to poorer ones; and economically supported, in the sense that a real cost function is minimized.

Many limitations arise because of the assumptions made, though. Firstly, the way fuel consumption is calculated can be fairly enriched with many other factors such as speed, road gradient, and so on. Secondly, parameters for the green taxes and green tolls can be also enchanted and plenty of sensitivity analysis can be performed in that direction. Finally, our results and conclusions are structured within a capacitated vehicle routing problem and may be not valid in any other variant. Therefore, those limitations make the base for the future research lines: richer variants of the VRP, more exhaustive fuel consumption estimation and deeper analysis in the parametrization.



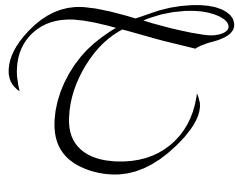
**PART V**

**FINAL CONCLUSIONS, FUTURE  
RESEARCH, AND CONTRIBUTIONS**



## CHAPTER 11.

# FINAL CONCLUSIONS, FUTURE RESEARCH, AND CONTRIBUTIONS



*his chapter concludes the thesis.*

*It is first summarized general conclusions from the development of this thesis in the two areas of interest: horizontal cooperation and environmental impacts in road freight transportation. Later, forthcoming research is identified. Finally, the list of contributions derived from this thesis is presented.*

## 1. Final conclusions

This thesis explores several aspects related to the logistics and transportation field. In particular, some important logistic decisions, such as vehicle routing and facility location, environmental impacts, and horizontal cooperation practices. Therefore, relevant conclusions can be obtained from the aspects reviewed.

Horizontal cooperation should be highly boosted in order to gain efficiency and sustainability. The proper management of concerted practices among companies in logistics activities enables significant savings in both costs and emissions as well as improvements in service quality. Nevertheless, several difficulties arise when dealing with horizontal cooperation. To this respect, trust issues has revealed itself as a huge barrier for achieving greater savings. Therefore, policy makers should focus on facilitating business relationships in all levels: operational, tactical, and strategic. Moreover, Operations Research techniques has been revealed as a critical decision support tool as the biorefinery location experience has highlighted. A joint investigation of supply and location decisions as well as mathematical modeling in close cooperation with relevant stakeholders enabled the project team to provide clear recommendations on the location of the biorefinery in Northern Spain. Additionally, insights were generated allowing decision-makers to discuss both economic and environmental impact of the considered actions. Therefore, models and input data were provided in a user-friendly framework to easily obtain detailed results, enabling decision-makers to investigate varying strategies in a flexible and risk-free manner. Additionally, the application of a real Facility Location Problem is highly motivated in the horizontal cooperation context. Decisions regarding sharing a consolidation center or opening a new one among members of a coalition need for a complete understanding of the Facility Location Problem characteristics.

Environmental impacts of transportation has to be seriously considered in logistics decision making. Traditional approaches are not valid anymore as our world is walking to a non-reversible climate change due to emissions. Therefore, the process of internalize transportation externalities such as air pollution would lead to decision makers to a greener operations. However, extreme caution should be paid at this point. On the one hand, the spread of the green vehicle routing problem philosophy in the academia is encouraging totally to abandon economic aspects to only focus on environmental ones such as minimization of emissions. Nevertheless, emissions can be always minimized if transportation is also minimized. Actually, there exists an extreme case in which no transportation is made at all, so emissions would down to zero. That it is not a desirable outcome, though. Multi objective approaches may be part of the solution but an explicit quantification of the non-economic objective is necessary for correctly evaluate the environmental impacts. Therefore, the internalization concept should gain a more relevant role in transportation decision-makings.

## 2. Future research

A number of research lines remains open after the conclusion of this research.

- a. Many research opportunities arise in the economic evaluation of environmental impacts. On the one hand, the development of a comprehensible model to easily evaluate environmental impacts is of utmost interest. Literature shows several models aiming at evaluating emissions and other externalities, however, they are extremely complex and data extensive. Moreover, pricing techniques are still in its infancy and an efficient, comprehensive, objective, and fair way to price is required. Economics concept such opportunity cost could be explored.
- b. Internalization of environmental costs is gaining importance. The increasing concerns regarding environmental issues are encouraging policy-makers to effectively change logistics decisions in a more sustainable way. Therefore, research on processes that allows inclusion of environmental costs in traditional costs remains as a gap in the transportation literature. To this respect, further research on properly defining green taxes and its effective application is definitely required.
- c. Multicriteria analysis as a powerful tool. Related to the previous points, multicriteria analysis offer a powerful tool in order to explore in both, qualitative and quantitative sides, the environmental consequences of the transportation activity.
- d. Finally, deeper research on horizontal cooperation is the other arena for upcoming research. In this way, the development of more powerful and realistic simulation models will finally determine and quantify cooperation benefits on both the environment and economics.

## 3. Contributions

This section lists scientific contributions derived from this thesis as well as a selection of conference communications. Finally, some research stays developed during the PhD studies are also shown.

### 3.1. JCR indexed papers

1. Alvarez, P., Lerga, I., **Serrano-Hernandez, A.**, and Faulin, J. (2018). The Impact of Traffic Congestion When Optimizing Delivery Routes in Real Time. A Case Study Using the Google Maps API in Spain. *International Journal of Logistics*: , accepted (ISI SCI, 2016 IF = 1.018, Q4; 2016 SJR = 0.512; Q2).



2. **Serrano-Hernandez, A.**, Juan, A., Faulin, J., Perez-Bernabeu, E. (2017) Horizontal collaboration in freight transport: concepts, benefits, and environmental challenges. *Statistics and Operational Research Transactions- SORT*, 41: 393-414 (ISI SCI, 2016 IF = 0.812, Q3; 2016 SJR = 0.526; Q2). Cover page available [JCR1].
3. **Serrano-Hernandez, A.**, Hirsch, P., Faulin, J. Fikar, C. Agent-Based Simulation for Horizontal Cooperation in Logistics and Transportation: from the Individual to the Grand Coalition. *Simulation Modelling, Practice and Theory*, under review, second round (ISI SCI 2016 IF = 1.954, Q2; 2016 SJR = 0.616; Q1).
4. Alvarez, P., Lerga, I., **Serrano-Hernandez, A.**, and Faulin, J. Is Time More Important Than Distance to Optimize Freight Delivery Routes? An Approach Using the Value of Time. *Journal of Advanced Transportation*, under review (ISI SCI, 2016 IF = 1.813, Q2; 2016 SJR = 0.752; Q1).
5. **Serrano-Hernandez, A.** and Faulin, J. Locating a Biorefinery in Northern Spain: Decision Making and Economic Consequences. *Socio Economic Planning Sciences*, under review (ISI SCI 2016 IF = 1.163, Q3; 2016 SJR = 0.534; Q2).
6. Alvarez, P., Lerga, I., **Serrano-Hernandez, A.**, and Faulin, J. Using technology to enhance urban logistics within smart cities. *Journal of Urban Technology*, under review (ISI SCI 2016 IF = 1.562, Q2; 2016 SJR = 0.674; Q1).
7. **Serrano-Hernandez, A.** and Faulin, J. Internalizing Negative Externalities in Vehicle Routing Problems through Green Taxes and Green Tolls. *International Journal of Logistics*, under review (ISI SCI 2016 IF = 1.018, Q4; 2016 SJR = 0.512; Q2).

### 3.2. Scopus indexed papers

1. **Serrano-Hernandez, A.**, Hirsch, P., Faulin, J. Fikar, C. (2018). The role of horizontal cooperation to improve service quality in last-mile distribution. *International Journal of Simulation and Process Modelling*, accepted (2016 CiteScore = 1.88, Q1).
2. **Serrano-Hernandez, A.**, Alvarez, P., Lerga, I., Reyes-Rubiano, L. and Faulin, J. (2017). Pricing and Internalizing Noise Externalities in Road Freight Transportation. *Transportation Research Procedia*, 27: 325–332 (2016 CiteScore = 0.82, Q3). Cover page available [SCP1].

3. **Serrano-Hernandez, A.**, Faulin, J., Pintor, J. and Belloso, J. (2017). Determining an Optimal Area to Locate a Biorefinery under Economic and Environmental Criteria. *Transportation Research Procedia*, 22: 95–104. (2016 CiteScore = 0.82, Q3). Cover page available [SCP2].
4. Alvarez, P., **Serrano-Hernandez, A.**, and Faulin, J. (2017). Considering Congestion Costs and Driver Behaviour into Route Optimisation Algorithms in Smart Cities. *Lecture Notes in Computer Science*, 10268: 39-50 (2016 CiteScore = 0.67, Q3). Cover page available [SCP3].
5. Saenz-Esteruelas, J., Figliozzi, M., **Serrano-Hernandez, A.**, and Faulin, J. (2016). Electrifying Last-Mile Deliveries: A Carbon Footprint Comparison between Internal Combustion Engine and Electric Vehicles. *Lecture Notes in Computers Science*, 9704: 76-84 (2016 CiteScore = 0.67, Q3). Cover page available [SCP4].
6. **Serrano-Hernandez, A.** Faulin, J., Astiz, P., Sanchez, M. and Belloso, J. (2015). Locating and designing a biorefinery supply chain under uncertainty in Navarre: a stochastic facility location problem case. *Transportation Research Procedia*, 10: 704-713. (2015 CiteScore = NA). Cover page available [SCP5].

### 3.3. Papers in non-indexed journals

1. Serrano-Hernandez, A. and Faulin, J. (2014). Using Probit and Tobit models to evaluate environmental costs in road transportation: a practical approach in the Pyrenees. *Journal of Applied Operational Research*, 8(1): 2-14. Cover page available [NIJ1].
2. Belloso, J. Juan. A., Faulin, J., and Serrano-Hernandez, A. (2015). Using multi-start biased randomization of heuristics to solve the vehicle routing problem with clustered backhauls. *Lecture Notes in Management Science*, 7: 15-20. Cover page available [NIJ2].
3. Ubeda, S., Faulin, J., Serrano-Hernandez, A., and Arcelus, F. (2014). Solving the green capacitated vehicle routing problem using a Tabu search algorithm. *Lecture Notes in Management Science*, 6: 141-149. Cover page available [NIJ3].

### 3.4. Conference proceedings indexed in Scopus

1. **Serrano-Hernandez, A.**, Faulin, J., Sanchez, M., Belloso, J., and Sawik, B. (2016). Locating a Biorefinery under Environmental Criteria: a Green Facility Location Problem. ICIL 2016 - 13 International conference on industrial logistics, conference proceedings, 28 September - 1 October, Zakopane, Poland (pp. 292-298), ISBN: 978-83-62079-06-3. Cover page available [CPR1].
4. **Serrano-Hernandez, A.**, Hirsch, P., Faulin, J. and Fikar C. (2016). Assessing service quality improvement through horizontal cooperation in last-mile distribution. In: Affenzeller, Bruzzone, Longo, Piera and Merkurjev (Eds.), Proceedings of the Int. Conf. on Harbor Maritime and Multimodal Logistics M&S, 35-41; ISBN: 978-88-97999-77-5 Cover page available [CPR2].

### 3.5. Contributions to conferences (selected)

<b>Authors</b>	Serrano-Hernandez A; Alvarez P; Lerga I; Reyes-Rubiano L; Faulin J.
<b>Title</b>	Pricing and internalizing noise externalities in road freight transportation.
<b>Conference</b>	EWGT2017. The 20th EURO Working Group on Transportation Meeting
<b>Place</b>	Budapest, Hungary
<b>Starting Date</b>	04/09/2017
<b>Authors</b>	Serrano-Hernandez A; Faulin J; Garcia del Valle A; Belloso J.
<b>Title</b>	Biorefinery Location And Green Perspectives.
<b>Conference</b>	INFORMS Annual Meeting 2016
<b>Place</b>	Nashville, USA
<b>Starting Date</b>	13/11/2016
<b>Authors</b>	Serrano-Hernandez A; Hirsch P; Faulin J; Fikar C.
<b>Title</b>	Assessing service quality improvement through horizontal cooperation in last-mile distribution.
<b>Conference</b>	The 18th International Conference on Harbor, Maritime & Multimodal Logistics Modelling and Simulation
<b>Place</b>	Larnaca, Cyprus
<b>Starting Date</b>	26/09/2016
<b>Authors</b>	Serrano-Hernandez A; Hirsch P; Faulin J; Fikar C.
<b>Title</b>	Designing a Biorefinery Supply Chain: a Real Case in Navarre (Spain).
<b>Conference</b>	INFORMS Annual Meeting 2015
<b>Place</b>	Philadelphia, USA
<b>Starting Date</b>	01/11/2015

### 3.6. Research Stays

<b>Receiving Institution</b>	University of Natural Resources and Life Sciences (BOKU) Institute of Production and Logistics
<b>Place</b>	Vienna, Austria
<b>Starting Date</b>	01/05/2017
<b>Duration</b>	3 months
<b>Funding</b>	Spanish Ministry of Education (grant EST16/00409). Erasmus+ (SmartTransLog@EU grant 2016-1-ES01-KA108-023465) EDONA (grant for predoctoral research stays)
<b>Receiving Institution</b>	University of Natural Resources and Life Sciences (BOKU) Institute of Production and Logistics
<b>Place</b>	Vienna, Austria
<b>Starting Date</b>	01/04/2016
<b>Duration</b>	1 month
<b>Funding</b>	<i>Caja Navarra</i> Foundation (grant for research stays)
<b>Receiving Institution</b>	Universitat Oberta de Catalunya Internet Interdisciplinary Institute
<b>Place</b>	Barcelona, Spain
<b>Starting Date</b>	01/03/2015
<b>Duration</b>	1 month
<b>Funding</b>	CYTED (grant CYTED2014-P514RT0013) <i>Caja Navarra</i> Foundation (grant for research stays)



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## APPENDIX A GAMS® MODEL FOR THE DSM

```
*****
****SETS****
*****

j potential locations /potLocation001*potLocation081/
i crops /crop001*crop354/
p product /rape, alfalfa, rice, corn, cereal/
t mes /january, february, march, april, may, june, july, august,
september, october, november, december/
k trucks /S,M,L/
*****
***PARAMETER***
*****

* Biomass related
production(i,p) total production of p in i
time(p,t) 1 if product p is available at t
harvest(p) season duration of product p
price(p) price of product p
a(i,p) exploitation factor of product p in i
h(p) humidity of product p

*Vehicle related
vehicleCapacity(k) capacity of vehicle k
FC(k) transportation fix cost of vehicle k
VC(k) transportation variable cost of vehicle k
gamma losses on transportation

*Biorefinery related*/
delta(t) losses on stock from time t to time t+1
consu biorefinery monthly consumption
sb stock costs at the biorefinery

*Others*/
distance(i,j) distance from crop i to potential location j

*****
**VARIABLES**
*****

totalCost

integer variable
V(k,i,j,t);
V.up(k,i,j,t)=10000000000;

positive variable
B(i,p,j,t,k) tons of product p bought in crop i at time t to serve
potential location j
```

BS(p,t,j) tons of product p bought in crop i at time t to serve potential location j

C(p,j,t) biorefinery j consumption of product p at time t

binary variable

x(j) 1 if the biorefinery is built in potential location j 0 otherwise

```
*****
****EQUATIONS****
*****
```

objective objective function

r1,r2,r3,r4,r5,r6,r7,r8,r9,r10,r11,r12,r13,r14,r15,r16;

```
objective.. totalCost =e= sum((i,p,j,t,k), B(i,p,j,t,k)*price(p))+
                        sum((k,i,j,t), FC(k)*V(k,i,j,t)+
VC(k)*2*V(k,i,j,t)*distance(i,j))+
                        sum((p,j,t), BS(p,t,j)*sb);;
```

```
r1.. sum(j, x(j)) =e= 1;
r2(p,j,"january").. sum((i,k), B(i,p,j,"january",k)*(1-gamma))+
BS(p,"december",j)*(1-delta("january")) =e= C(p,j,"january")/(1-h(p))+
BS(p,"january",j);
r3(p,j,"february").. sum((i,k), B(i,p,j,"february",k)*(1-gamma))+
BS(p,"january",j)*(1-delta("february")) =e= C(p,j,"february")/(1-
h(p))+ BS(p,"february",j);
r4(p,j,"march").. sum((i,k), B(i,p,j,"march",k)*(1-gamma))+
BS(p,"february",j)*(1-delta("march")) =e= C(p,j,"march")/(1-h(p))+
BS(p,"march",j);
r5(p,j,"april").. sum((i,k), B(i,p,j,"april",k)*(1-gamma))+
BS(p,"march",j)*(1-delta("april")) =e= C(p,j,"april")/(1-h(p))+
BS(p,"april",j);
r6(p,j,"may").. sum((i,k), B(i,p,j,"may",k)*(1-gamma))+
BS(p,"april",j)*(1-delta("may")) =e= C(p,j,"may")/(1-h(p))+
BS(p,"may",j);
r7(p,j,"june").. sum((i,k), B(i,p,j,"june",k)*(1-gamma))+
BS(p,"may",j)*(1-delta("june")) =e= C(p,j,"june")/(1-h(p))+
BS(p,"june",j);
r8(p,j,"july").. sum((i,k), B(i,p,j,"july",k)*(1-gamma))+
BS(p,"june",j)*(1-delta("july")) =e= C(p,j,"july")/(1-h(p))+
BS(p,"july",j);
r9(p,j,"august").. sum((i,k), B(i,p,j,"august",k)*(1-gamma))+
BS(p,"july",j)*(1-delta("august")) =e= C(p,j,"august")/(1-h(p))+
BS(p,"august",j);
r10(p,j,"september")..sum((i,k), B(i,p,j,"september",k)*(1-
gamma))+BS(p,"august",j)*(1-delta("september")) =e=
C(p,j,"september")/(1-h(p))+BS(p,"september",j);
r11(p,j,"october").. sum((i,k), B(i,p,j,"october",k)*(1-gamma))+
BS(p,"september",j)*(1-delta("october"))=e= C(p,j,"october")/(1-h(p))+
BS(p,"october",j);
```

```

r12(p,j,"november").. sum((i,k), B(i,p,j,"november",k)*(1-gamma))+
BS(p,"october",j)*(1-delta("november")) =e= C(p,j,"november")/(1-
h(p))+ BS(p,"november",j);
r13(p,j,"december").. sum((i,k), B(i,p,j,"december",k)*(1-gamma))+
BS(p,"november",j)*(1-delta("december"))=e= C(p,j,"december")/(1-
h(p))+ BS(p,"december",j);
r14(i,p,j,t).. sum(k, B(i,p,j,t,k)) =l=
(production(i,p)*a(i,p)*(time(p,t)/harvest(p)));
r15(j,t)..sum(p, C(p,j,t))=e=consu*x(j);
r16(k,i,j,t).. (V(k,i,j,t)) =g= sum(p,
B(i,p,j,t,k)/vehicleCapacity(k));

```

```

*****
***Options***
*****

```

```

biorefinery.dictfile=0;
$onecho >cplex.opt
lpmethod=1
memoryemphasis=1
names=0
nodefileind=3
$offecho
option reslim=10000;
option solvelink=0;
option solprint=off
$OFFFLISTING;
$OFFSYMLIST;
$OFFSYMXXREF;
$OFFFUELLIST;
$OFFFUELXREF;

```

```

*****
***SOLVING***
*****

```

```

model biorefinery /all/;
solve biorefinery using mip min totalcost;

display x.l,B.l, BS.l, V.l;

```

```

*****
***REPORTING***
*****
parameters
BiomassCosts
TransportCosts
BioStorageCosts
Distances
TotalCosts;

```

```
BiomassCosts=sum((i,p,j,t,k), B.l(i,p,j,t,k)*price(p));
TransportCosts= sum((k,i,j,t), FC(k)*V.l(k,i,j,t)+
VC(k)*2*V.l(k,i,j,t)*distance(i,j));
BioStorageCosts= sum((p,j,t), BS.l(p,t,j)*sb);
Distances= sum((k,i,j,t), 2*V.l(k,i,j,t)*distance(i,j));
TotalCosts= BiomassCosts+TransportCosts+BioStorageCosts;
```

```
parameter report(*);
report("Biomass Costs")=BiomassCosts;
report("Transport Costs")= TransportCosts;
report("Bio Storage Costs")= BioStorageCosts;
report("Total Dist")= Distances;
report("Total Costs")= TotalCosts;
display report;
```



**APPENDIX B GAMS® MODEL FOR THE ICM**

```
*****
****SETS****
*****
```

```
j potential locations /potLocation001*potLocation081/
i crops /crop001*crop354/
p product /rape, alfalfa, rice, corn, cereal/
t mes /january, february, march, april, may, june, july, august,
september, october, november, december/
w intermediate collector /intCol001*intCol079/
```

```
*****
****PARAMETERS***
*****
```

```
* Biomass related
production(i,p) total production of p in i
time(p,t) 1 if product p is available at t
harvest(p) season duration of product p
price(p) price of product p
a(i,p) exploitation factor of product p in i
h(p) humidity of product p
```

```
* Vehicle Related
vehicleCapacityL
FCL
VCL
vehicleCapacityM
FCM
VCM
vehicleCapacityS
FCS
VCS
gamma losses on transportation
```

```
* Biorefinery related
delta(t) losses on stock from time t to time t+1
consu biorefinery monthly consumption
sb stock cost at biorefinery
beta proportion of consumption which can be stock at the bio
consu biorefinery monthly consumption
```

```
* Intermediate collector related
sc stock cost at intermediate-collector
rent cost of setting up an intermediate-collectors
cap(w) capacity of intermediate-collectors
```

```
*others
Dij distance from crop i to potential location j
Diw distance from crop i to intermediate collector w
```

```

Dwj distance from intermediate collector w to potential location j

*****
***VARIABLES***
*****

totalCost

integer variable
Vij(i,j,t) Number of large trucks going from crop i to biorefinery j
at time t
Viw(i,w,t) Number of small trucks going from crop i to w at time t
Vwj(w,j,t) Number of medium trucks going from w to biorefinery j at
time t ;
Vij.up(i,j,t)=100000000000;
Viw.up(i,w,t)=100000000000;
Vwj.up(w,j,t)=100000000000;

positive variable
B(p,i,t) Tons of product p bought in crop i at time t j
Qiw(p,i,w,t) Tons of product p bought in crop i transported to
biorefinery j at time t
Qij(p,i,j,t) Tons of product p bought in crop i transported to w at
time t
Qwj(p,w,j,t) Tons of product p in w transported to biorefinery j at
time t
CS(p,w,t) Stock corresponding to intermediate-collector w of product p
at time t
BS(p,j,t) Stock corresponding to potential location j of product p at
time t in
C(p,j,t) Biorefinery j consumption of product p at time t

binary variable
x(j)
y(w)

*****
***EQUATIONS***
*****

objetive objective function
r1,r2, r3,
r4,r5,r6,r7,r8,r9,r10,r11,r12,r13,r14,r15,r16,r17,r18,r19,r20,r21,r22,
r23,r24,r25,r26,r27,r28,r29,r30,r31,r32,r33,r34;

objetive.. totalCost =e= sum((p,i,t), B(p,i,t)*price(p))
+ sum((i,j,t), FCL*Vij(i,j,t)+
VCL*2*Vij(i,j,t)*Dij(i,j))
+ sum((i,w,t), FCS*Viw(i,w,t)+
VCS*2*Viw(i,w,t)*Diw(i,w))
+ sum((w,j,t), FCM*Vwj(w,j,t)+
VCM*2*Vwj(w,j,t)*Dwj(w,j))

```

```

+ sum((p,j,t), BS(p,j,t)*sb)
+ sum((p,w,t), CS(p,w,t)*sc)+ sum(w,
rent*y(w));

r1.. sum(j, x(j))=e=1 ;
r2(p,i,t)..
B(p,i,t)=l=(production(i,p)*a(i,p)*(time(p,t)/harvest(p)));
r3(p,i,t).. B(p,i,t)=e= sum(w, Qiw(p,i,w,t))+ sum(j, Qij(p,i,j,t));
r4(p,w,"january").. sum(i, Qiw(p,i,w,"january")*(1-gamma))+ (1-
delta("january"))* CS(p,w,"december")=e=sum(j, Qwj(p,w,j,"january"))+
CS(p,w,"january");
r5(p,w,"february").. sum(i, Qiw(p,i,w,"february")*(1-gamma))+ (1-
delta("february"))* CS(p,w,"january") =e=sum(j,
Qwj(p,w,j,"february"))+ CS(p,w,"february");
r6(p,w,"march").. sum(i, Qiw(p,i,w,"march")*(1-gamma))+ (1-
delta("march"))* CS(p,w,"february") =e=sum(j, Qwj(p,w,j,"march"))+
CS(p,w,"march");
r7(p,w,"april").. sum(i, Qiw(p,i,w,"april")*(1-gamma))+ (1-
delta("april"))* CS(p,w,"march") =e=sum(j, Qwj(p,w,j,"april"))+
CS(p,w,"april");
r8(p,w,"may").. sum(i, Qiw(p,i,w,"may")*(1-gamma))+ (1-
delta("may"))* CS(p,w,"april") =e=sum(j, Qwj(p,w,j,"may"))+
CS(p,w,"may");
r9(p,w,"june").. sum(i, Qiw(p,i,w,"june")*(1-gamma))+ (1-
delta("june"))* CS(p,w,"may") =e=sum(j, Qwj(p,w,j,"june"))+
CS(p,w,"june");
r10(p,w,"july").. sum(i, Qiw(p,i,w,"july")*(1-gamma))+ (1-
delta("july"))* CS(p,w,"june") =e=sum(j, Qwj(p,w,j,"july"))+
CS(p,w,"july");
r11(p,w,"august").. sum(i, Qiw(p,i,w,"august")*(1-gamma))+ (1-
delta("august"))* CS(p,w,"july") =e=sum(j, Qwj(p,w,j,"august"))+
CS(p,w,"august");
r12(p,w,"september").. sum(i, Qiw(p,i,w,"september")*(1-gamma))+ (1-
delta("september"))*CS(p,w,"august") =e=sum(j,
Qwj(p,w,j,"september"))+ CS(p,w,"september");
r13(p,w,"october").. sum(i, Qiw(p,i,w,"october")*(1-gamma))+ (1-
delta("october"))* CS(p,w,"september")=e=sum(j,
Qwj(p,w,j,"october"))+ CS(p,w,"october");
r14(p,w,"november").. sum(i, Qiw(p,i,w,"november")*(1-gamma))+ (1-
delta("november"))* CS(p,w,"october") =e=sum(j,
Qwj(p,w,j,"november"))+ CS(p,w,"november");
r15(p,w,"december").. sum(i, Qiw(p,i,w,"december")*(1-gamma))+ (1-
delta("december"))* CS(p,w,"november") =e=sum(j,
Qwj(p,w,j,"december"))+ CS(p,w,"december");
r16(w,t).. sum((p), CS(p,w,t))=l=cap(w)*y(w);
r17(p,j,"january").. sum(i, Qij(p,i,j,"january")*(1-gamma))+
sum(w,Qwj(p,w,j,"january"))+ (1-delta("january"))*
BS(p,j,"december") =e=C(p,j,"january") +BS(p,j,"january");
r18(p,j,"february").. sum(i, Qij(p,i,j,"february")*(1-gamma))+
sum(w,Qwj(p,w,j,"february"))+ (1-delta("february"))* BS(p,j,"january")
=e=C(p,j,"february") +BS(p,j,"february");

```



```

r19(p,j,"march")..      sum(i, Qij(p,i,j,"march")*(1-gamma))+
sum(w,Qwj(p,w,j,"march"))+      (1-delta("march"))*
BS(p,j,"february") =e=C(p,j,"march")      +BS(p,j,"march");
r20(p,j,"april")..      sum(i, Qij(p,i,j,"april")*(1-gamma))+
sum(w,Qwj(p,w,j,"april"))+      (1-delta("april"))*      BS(p,j,"march")
=e=C(p,j,"april")      +BS(p,j,"april");
r21(p,j,"may")..      sum(i, Qij(p,i,j,"may")*(1-gamma))+
sum(w,Qwj(p,w,j,"may"))+      (1-delta("may"))*      BS(p,j,"april")
=e=C(p,j,"may")      +BS(p,j,"may");
r22(p,j,"june")..      sum(i, Qij(p,i,j,"june")*(1-gamma))+
sum(w,Qwj(p,w,j,"june"))+      (1-delta("june"))*      BS(p,j,"may")
=e=C(p,j,"june")      +BS(p,j,"june");
r23(p,j,"july")..      sum(i, Qij(p,i,j,"july")*(1-gamma))+
sum(w,Qwj(p,w,j,"july"))+      (1-delta("july"))*      BS(p,j,"june")
=e=C(p,j,"july")      +BS(p,j,"july");
r24(p,j,"august")..      sum(i, Qij(p,i,j,"august")*(1-gamma))+
sum(w,Qwj(p,w,j,"august"))+      (1-delta("august"))*      BS(p,j,"july")
=e=C(p,j,"august")      +BS(p,j,"august");
r25(p,j,"september").. sum(i, Qij(p,i,j,"september")*(1-gamma))+
sum(w,Qwj(p,w,j,"september"))+(1-delta("september"))*BS(p,j,"august")
=e=C(p,j,"september")+BS(p,j,"september");
r26(p,j,"october")..   sum(i, Qij(p,i,j,"october")*(1-gamma))+
sum(w,Qwj(p,w,j,"october"))+      (1-delta("october"))*
BS(p,j,"september")=e=C(p,j,"october")      +BS(p,j,"october");
r27(p,j,"november")..  sum(i, Qij(p,i,j,"november")*(1-gamma))+
sum(w,Qwj(p,w,j,"november"))+      (1-delta("november"))*      BS(p,j,"october")
=e=C(p,j,"november")      +BS(p,j,"november");
r28(p,j,"december")..  sum(i, Qij(p,i,j,"december")*(1-gamma))+
sum(w,Qwj(p,w,j,"december"))+      (1-delta("december"))*
BS(p,j,"november") =e=C(p,j,"december")      +BS(p,j,"december");
r29(j,t)..sum(p, C(p,j,t))=e=consu*x(j);
r30(j,t).. sum(p, BS(p,j,t))=l=beta*consu*x(j);
r31(w).. cap(w)=l= 20000;
r32(i,j,t).. (Vij(i,j,t)) =g= sum(p, Qij(p,i,j,t)/vehicleCapacityL);
r33(i,w,t).. (Viw(i,w,t)) =g= sum(p, Qiw(p,i,w,t)/vehicleCapacityS);
r34(w,j,t).. (Vwj(w,j,t)) =g= sum(p, Qwj(p,w,j,t)/vehicleCapacityM);

```

```

*****
***Options***
*****

```

```

biorefinery.dictfile=0;
$onecho >cplex.opt
lpmethod=1
memoryemphasis=1
names=0
nodefileind=3
$offecho
option reslim=10000;
option solvelink=0;
option solprint=off
$OFFFLISTING;

```

```

$OFFSYMLIST;
$OFFSYMXPREF;
$OFFFUELLIST;
$OFFFUELXPREF;

*****
***SOLVING***
*****

model biorefinery /all/;
solve biorefinery using mip min totalcost;
display Vij.l, Viw.l, Vwj.l, B.l, Qiw.l, Qij.l, Qwj.l, CS.l, BS.l,
C.l, x.l, y.l;

*****
***REPORTING***
*****

parameter
BiomassCosts
TransportCosts
BioStorageCosts
ICStorageCosts
SetupICCosts
DistanceCropBio
DistanceCropIC
DistanceICBio
TotalDist
TotalCosts;

BiomassCosts=sum((p,i,t), B.l(p,i,t)*price(p));
TransportCosts= sum((i,j,t), FCL*Vij.l(i,j,t)+
VCL*2*Vij.l(i,j,t)*Dij(i,j))
+ sum((i,w,t), FCS*Viw.l(i,w,t)+
VCS*2*Viw.l(i,w,t)*Diw(i,w))
+ sum((w,j,t), FCM*Vwj.l(w,j,t)+
VCM*2*Vwj.l(w,j,t)*Dwj(w,j));
BioStorageCosts= sum((p,j,t), BS.l(p,j,t)*sb);
ICStorageCosts= sum((p,w,t), CS.l(p,w,t)*sc);
SetupICCosts= sum(w, rent*y.l(w));
DistanceCropBio= sum((i,j,t), 2*Vij.l(i,j,t)*Dij(i,j));
DistanceCropIC= sum((i,w,t), 2*Viw.l(i,w,t)*Diw(i,w));
DistanceICBio= sum((w,j,t), 2*Vwj.l(w,j,t)*Dwj(w,j));
TotalDist= DistanceCropBio+ DistanceCropIC+DistanceICBio ;
TotalCosts=
BiomassCosts+TransportCosts+BioStorageCosts+ICStorageCosts+SetupICCost
s;

parameter report(*);
report("Biomass Costs")=BiomassCosts;

```

```
report("Transport Costs")= TransportCosts;  
report("Bio Storage Costs")= BioStorageCosts;  
report("IC Storage Costs")= ICStorageCosts;  
report("Setup IC Costs")= SetupICCosts;  
report("Distance CropBio")= DistanceCropBio;  
report("Distance CropIC")= DistanceCropIC;  
report("DistanceICBio")= DistanceICBio;  
report("Total Dist")= TotalDist;  
report("Total Costs")= TotalCosts;  
display report;
```



## APPENDIX C: COVER PAGE OF PUBLISHED ARTICLES

[JCR1] Serrano-Hernandez, A., Juan, A., Faulin, J., Perez-Bernabeu, E. (2017) Horizontal collaboration in freight transport: concepts, benefits, and environmental challenges. *Statistics and Operational Research Transactions- SORT*, 41: 393-414.

SORT 41 (2) July-December 2017, 393-414

DOI: 10.2436/20.8080.02.65

### Horizontal collaboration in freight transport: concepts, benefits, and environmental challenges

Adrián Serrano-Hernández<sup>1</sup>, Angel A. Juan<sup>2</sup>, Javier Faulin<sup>1</sup>  
and Elena Perez-Bernabeu<sup>3</sup>

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#### Abstract

Since its appearance in the 1990s, horizontal collaboration (HC) practices have revealed themselves as catalyzers for optimizing the distribution of goods in freight transport logistics. After introducing the main concepts related to HC, this paper offers a literature review on the topic and provides a classification of best practices in HC. Then, the paper analyses the main benefits and optimization challenges associated with the use of HC at the strategic, tactical, and operational levels. Emerging trends such as the concept of 'green' or environmentally-friendly HC in freight transport logistics are also introduced. Finally, the paper discusses the need of using hybrid optimization methods, such as simheuristics and learnheuristics, in solving some of the previously identified challenges in real-life scenarios dominated by uncertainty and dynamic conditions.

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MSC: 90B06.

**Keywords:** Horizontal collaboration, freight transport, sustainable logistics, supply chain management, combinatorial optimization.

#### 1. Introduction

Terms such as 'joint venture', 'network', 'alliance', 'coalition', 'cooperation', 'agreement', or 'partnership' are frequently used in modern business activities. Due to their relevance, they are often accompanied by the 'strategic' adjective. Specifically, the concepts of 'cooperation' and 'collaboration' are occasionally used as synonymous by some authors (as it will be the case in this paper), while others consider that the latter extends the former by also including mutual trust, a higher stage of commitment, etc. Several researchers have tried to rank these terms, obtaining different results depending on the economic sector and criteria considered (Mentzer, Foggin and Golicic, 2000; Golicic, Foggin and Mentzer 2003). As Barratt (2004) concluded, "cooperation is an amorphous

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<sup>1</sup> Corresponding author. Dept. of Statistics and OR, Institute of Smart Cities, Public University of Navarre, Spain. [adrian.serrano@unavarra.es](mailto:adrian.serrano@unavarra.es), [javier.faulin@unavarra.es](mailto:javier.faulin@unavarra.es)

<sup>2</sup> IN3 – Computer Science Dept., Open University of Catalonia, Spain. [ajuana@uoc.edu](mailto:ajuana@uoc.edu)

<sup>3</sup> Dept. of Applied Statistics, OR and Quality, Universitat Politècnica de Valencia, Spain. [elenapb@cio.upv.es](mailto:elenapb@cio.upv.es)

Received: March 2017

Accepted: October 2017

[SCPI] Serrano-Hernandez, A., Alvarez, P., Lerga, I., Reyes-Rubiano, L. and Faulin, J. (2017). Pricing and Internalizing Noise Externalities in Road Freight Transportation. *Transportation Research Procedia*, 27: 325–332.



Available online at [www.sciencedirect.com](http://www.sciencedirect.com)

**ScienceDirect**

Transportation Research Procedia 27 (2017) 325–332



20th EURO Working Group on Transportation Meeting, EWGT 2017, 4-6 September 2017, Budapest, Hungary

## Pricing and Internalizing Noise Externalities in Road Freight Transportation

Adrián Serrano-Hernández<sup>a,\*</sup>, Pablo Álvarez<sup>a</sup>, Iosu Lerga<sup>a</sup>, Lorena Reyes-Rubiano<sup>a</sup>, and Javier Faulin<sup>a</sup>.

<sup>a</sup> Institute of Smart Cities. Integrated Group of Logistics and Transportation. Public University of Navarra, 31006 Pamplona, SPAIN.

### Abstract

People living close to main roads may suffer from the nuisance of traffic and noise pollution. This paper assesses the effect of full routing cost in vehicle routing decisions by internalizing the external cost of noise. On a first step, noise externalities are economically assessed through a contingent valuation procedure. Secondly, a novel methodology is proposed to allocate the external costs to the road network links. Results show significant differences in routing planning depending on the approach: minimization of traditional internal cost versus minimization of full cost. These results encourage further research in pricing and methodologies to internalize externalities.

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Peer-review under responsibility of the scientific committee of the 20th EURO Working Group on Transportation Meeting.

**Keywords:** Externality; Contingent Valuation Methodology; Noise; Internalization; Pricing; Vehicle Routing Problem

### 1. Introduction

According to the **European Commission (2016)**, half of all goods in Europe are moved using road transportation, being the responsible of 5% of the European GDP and employing about 3 million people. Furthermore, road freight transportation accounts for 24% of all greenhouse gases emitted in the European Union which contributed to global warming and it is also source of stress, sleep disturbance and other noise-related issues. Therefore, research on road transportation economic, social, and environmental impacts is of utmost interest.

\* Corresponding author. Tel.: +34-948169213.

E-mail address: [adrian.serrano@unavarra.es](mailto:adrian.serrano@unavarra.es)

[SCP2] Serrano-Hernandez, A., Faulin, J., Pintor, J. and Belloso, J. (2017). Determining an Optimal Area to Locate a Biorefinery under Economic and Environmental Criteria. *Transportation Research Procedia*, 22: 95–104.



Available online at [www.sciencedirect.com](http://www.sciencedirect.com)

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Transportation Research Procedia 22 (2017) 95–104

Transportation  
Research  
**Procedia**  
[www.elsevier.com/locate/procedia](http://www.elsevier.com/locate/procedia)

19th EURO Working Group on Transportation Meeting, EWGT2016, 5-7 September 2016,  
Istanbul, Turkey

## Determining an Optimal Area to Locate a Biorefinery under Economic and Environmental Criteria

Adrian Serrano-Hernandez<sup>a,\*</sup>, Javier Faulin<sup>a</sup>, Jesús M. Pintor<sup>a</sup> and Javier Belloso<sup>a</sup>

<sup>a</sup>*Integrated Group of Logistics and Transportation, Institute of Smart Cities, Public University of Navarre, Pamplona 31006, Spain*

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### Abstract

Facilities location is a strategic decision which has to be carefully considered because it could involve the failure or success of a business. For that reason, anything that helps decision makers to facilitate their location decision processes is of their utmost interest. The aim of this paper is, therefore, providing a methodology that could be useful for the decision makers by giving them not only an optimal point but also a whole region where they can focus on their attention. Knowing that biofuels are settling as a new alternative energy source which has been spreading around the world to reduce greenhouse gas emissions and oil dependence, this methodology is tested in the real case of locating a biorefinery in Navarre, Spain. Moreover, A Mixed Integer Linear Programming (MILP) model has been developed to generate optimal region vertices as well as some other supply chain characteristics, including, among others, which crops are going to be harvested, when they are going to be collected, and their storage levels. Additionally, two criteria were implemented in MILP model to create two optimal regions: one considering an economic criterion and other one minimizing environmental impact. As a result, two regions were drawn in the Navarrese territory that point out where a biorefinery should be located and how the supply chain should be designed.

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Peer-review under responsibility of the Scientific Committee of EWGT2016.

**Keywords:** Facility Location Problem; Biorefinery; Mixed Integer Linear Programming; Biofuels

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\* Corresponding author. Tel.: +34-948168965; fax: +34-948169204.  
E-mail address: [adrian.serrano@unavarra.es](mailto:adrian.serrano@unavarra.es)

[SCP3] Alvarez, P., Serrano-Hernandez, A., and Faulin, J. (2017). Considering Congestion Costs and Driver Behaviour into Route Optimisation Algorithms in Smart Cities. *Lecture Notes in Computer Science*, 10268: 39-50.



## Considering Congestion Costs and Driver Behaviour into Route Optimisation Algorithms in Smart Cities

Pablo Alvarez<sup>(✉)</sup>, Iosu Lerga, Adrian Serrano, and Javier Faulin

Department of Statistics and OR, Institute of Smart Cities,  
Public University of Navarra, Pamplona, Spain  
{pablo.alvarez,iosu.lerga,adrian.serrano,  
javier.faulin}@unavarra.es

**Abstract.** Congestion costs have been excluded from the study of traditional vehicle routing problems until very recently. However, with our urban areas experiencing higher levels of traffic congestion, with the increase in on-demand deliveries, and with the growth of intelligent transport systems and smart cities, researchers are raising awareness on the impact that traffic congestion and driver behaviour has for urban logistics. This paper studies the evolution of the vehicle routing problem, focusing on how traffic congestion costs and driver behaviour effects have been considered so far, and analysing how the research community has to deal with this challenge.

**Keywords:** Vehicle routing problem · Congestion · Driver behaviour · Smart cities · Big Data

### 1 Introduction

The Vehicle Routing Problem (VRP) is one of the recurring topics existing in the literature on transport and logistics activities [1]. In 1954, Dantzig, Fulkerson, and Johnson wrote a seminal paper [2] to solve a large-scale traveling salesman problem (TSP). However, it was in 1959 when Dantzig and Ramser [3] developed the first algorithmic approach applied to optimise delivery routes between petrol stations. This was the first record related to a VRP, as we know it today, although it was later improved (in 1964) by Clarke and Wright [4] to solve a problem in which a fleet of trucks of different capacities had to be used for delivery from a central depot to several delivery points. A few years later, different versions of VRP emerged and were applied to different fields such as fleet routing [5], bus routing [6], or waste collection [7]. However, it was not until 1972 when the words “*vehicle routing*” appeared together in the title of a research work by Golden, Magnanti and Nguyen [8], in which they used heuristic programming to develop a multi-depot routing algorithm. In that period, researchers tried to solve the problems in a more realistic way, using more constraints such as vehicle capacity, time windows, or different fleet configurations.

The possibilities to study more realistic variations of VRP were limited due to the computational complexity required, and it was not until the 1990s when research on

© Springer International Publishing AG 2017  
E. Alba et al. (Eds.): Smart-CT 2017, LNCS 10268, pp. 39–50, 2017.  
DOI: 10.1007/978-3-319-59513-9\_5

[SCP4] Saenz-Esteruelas, J., Figliozzi, M., Serrano-Hernandez, A., and Faulin, J. (2016). Electrifying Last-Mile Deliveries: A Carbon Footprint Comparison between Internal Combustion Engine and Electric Vehicles. *Lecture Notes in Computers Science*, 9704: 76-84.

# Electrifying Last-Mile Deliveries: A Carbon Footprint Comparison between Internal Combustion Engine and Electric Vehicles

Jesus Saenz-Esteruelas<sup>1</sup>✉, Miguel Figliozzi<sup>2</sup>, Adrian Serrano<sup>1</sup>, and Javier Faulin<sup>1</sup>

<sup>1</sup> Department of Statistics and OR, Public University of Navarra, Pamplona, Spain  
{jesusmaria.saenz, adrian.serrano, javier.faulin}@unavarra.es

<sup>2</sup> Department of Civil and Environmental Engineering,  
Portland State University, Portland, OR, USA  
figliozzi@pdx.edu

**Abstract.** Last-mile management distribution is a growing challenge in big cities that affects to quality of life of many citizens. A way to mitigate greenhouse gas (GHG) emissions and congestion, as well as to promote and develop Smart Cities, is electrifying urban distribution by means of electric tricycles. This article evaluates the GHG of a tricycle logistics company (B-Line) in downtown Portland, OR. The goal is to analyze carbon footprint potential savings between electric tricycle last-mile distribution against a traditional diesel-powered van system. Real-world GPS and warehouse data were collected to assess B-Line operations. Results show a huge GHG emissions reduction, being tricycle logistic system twice more efficient than the traditional one.

**Keywords:** Smart city · Externality · Electric vehicle · Last-mile distribution

## 1 Introduction

Cities are evolving towards sustainability and efficiency; cities are moving to be smart. Globalization and the constant growth of world trade [1] have made transportation a key sector and a major contributor to progress and development. However, transportation activities frequently make indirect negative impacts on the environment such as air pollution and noise, usually named externalities. At the same time, people are concentrating around major urban areas. Actually, more than 50 % of world's population in 2014 lived in urban areas [2] what implies a high number of commercial deliveries in cities [3]. Consequently, commercial vehicles presence in urban areas has dramatically increased as some studies showed that vehicle miles of travel has rose 20 % from 1996 to 2006 [4].

Indirect effects of an economic activity are said to be externalities since those are out of the price system [5]. Research interest in externalities of freight transportation has continuously expanded because of the increasing impacts on economy, environment, climate, and society. Air pollution, noise, congestion, road damage and accidents are the usual externalities related to transport activities, nevertheless, due to the fact that

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E. Alba et al. (Eds.): Smart-CT 2016, LNCS 9704, pp. 76–84, 2016.  
DOI: 10.1007/978-3-319-39595-1\_8

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Available online at [www.sciencedirect.com](http://www.sciencedirect.com)

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Transportation Research Procedia 10 (2015) 704 – 713



18th Euro Working Group on Transportation, EWGT 2015, 14-16 July 2015,  
Delft, The Netherlands

## Locating and designing a biorefinery supply chain under uncertainty in Navarre: a stochastic facility location problem case

Adrián Serrano\*, Javier Faulin, Pablo Astiz, Mercedes Sánchez, Javier Beloso.

Interdisciplinary Group of Logistics and Transportation- GILT, Public University of Navarre, Spain

### Abstract

The need for renewable energy sources is quickly growing in order to reduce the greenhouse gas emissions. Moreover, Navarre, a European region located in Northern Spain is, currently, a global leader in the production and use of renewable energy. Actually, more than 80% of its electricity production comes from renewable sources (mainly wind and water). Then, having the purpose of increasing the renewable energy sources diversification, the region aims to locate a biorefinery plant which mainly serves Northern Spain. Locating decisions are considered strategic, immobilizing a large amount of resources and involving an important group of industrial actors. Therefore, they initially show a significant impact on investment costs, and later, on the operating costs when the facility is already running. This location activity has also important environmental influence due to the usual performance of the biorefinery, involving also the transportation and logistic activities because of the supply chain procurement. Once the biorefinery has been located, another problem arises: the design of the supply chain with its classical operational decisions: which crops are going to be harvested, when they are going to be collected and how we should transport the feedstock to the biorefinery. Apart from this, dealing with farms production is always dealing with uncertainty. Thus, climate and weather, competitors and alternate uses, are key factors which influence the availability of biomass. For that reason, uncertainty must be taken into account in order to avoid stockouts that allow us the optimization of the total expected cost. Moreover, estimated feedstock availability is crucial to determine the optimal plant size. Therefore, the results provide us not only the best location of the biorefinery from the economic point of view, but also the variation on feedstock disposal that eventually the biorefinery could intake along with its final size.

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Peer-review under responsibility of Delft University of Technology

**Keywords:** Facility Location Problem; Biorefinery; Uncertainty; Mixed Integer Linear Programming Problem; Biomass.

\* Corresponding and presenting author. Tel.: +34-948168965; fax: +34-948169204.

E-mail address: [adrian.serrano@unavarra.es](mailto:adrian.serrano@unavarra.es)

[NIJ1] Serrano-Hernandez, A. and Faulin, J. (2014). Using Probit and Tobit models to evaluate environmental costs in road transportation: a practical approach in the Pyrenees. *Journal of Applied Operational Research*, 8(1): 2-14.

*Journal of Applied Operational Research* (2016) Vol. 8, No. 1, 2–14

ISSN 1735-8523 (Print), ISSN 1927-0089 (Online)

[www.orlabanalytics.com](http://www.orlabanalytics.com)

## Using Probit and Tobit models to evaluate environmental costs in road transportation: a practical approach in the Pyrenees

Adrian Serrano-Hernandez<sup>1,\*</sup> and Javier Faulin<sup>1</sup>

<sup>1</sup> Public University of Navarre, Spain

Received 29 December 2015  
Accepted 07 March 2016

### Keywords:

Air pollution  
Contingent valuation method  
Externalities  
Noise  
Probit model  
Tobit model  
Willingness to pay

**Abstract**—The neighbors of the usual routes of transportation suffer from the effects of the continuous movement of vehicles on the roads close to their homes. Although, it is possible to evaluate economically these externalities in many different ways, this paper proposes the use of a contingent valuation method derived from a survey developed in the Spanish side of the Pyrenees. The respondents were asked for their willingness to pay (WTP) for different levels of pollution and noise presented in hypothetical scenarios. The survey also contains questions about socio-economic, ecological and demographic variables, among others, in order to enrich the WTP results. Therefore, this paper focuses on extracting information from the results of surveys using two models (Tobit and Probit) to obtain estimations of environmental costs (pollution and noise). Noting that people with the characteristics depicted as 'young, man, better educated, higher income and having more environmental concern' are willing to pay more. A high detailed level is a special point in this paper since those models allow us to compute meaningful marginal effects.

Published 01 December 2016

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## Introduction

Nowadays, transportation is a key sector of the economy and a major contributor to social and economic progress in the world due to its recent growth and obvious importance in modern societies. In the European Union, freight transportation accounts for more than €250,000 million in 2014, which is about 3% EU GDP (Eurostat, 2014a), and 6 millions of jobs (Eurostat, 2014b). However, transportation also has negative consequences, for instance, noise, air pollution, vibration, etc. Moreover, indirect impacts include many other phenomena, such as, traffic jams and changes in citizens' behavior (i.e. anxiety and stress). All these negative influences are known as externalities which are, generally speaking, the indirect effects of consumption or production activity on the utility function of a consumer or a producer. Those effects are called indirect because they do not concern the agents involved in such an economic activity and they are not reflected in the price system (Laffont, 2008). Finally, the externalities are deeply embedded and connected into a complex ecological and sociological network (Lera-López *et al.*, 2014a).

The road transportation, as the primary mode of freight movement, is the largest source of freight-related CO<sub>2</sub> emissions in developed countries (Intergovernmental Panel on Climate Change, 2007). That is, the CO<sub>2</sub> emissions in transport sector and their contribution to climate change are one of the main problems in the sustainable management of logistic activities. Road transportation is the most polluting activity in Spain in 2013, even more than energy industries, being responsible for more than 25% of total greenhouse emissions (GHE) (Spain in Figures, 2013). In Europe, the road transportation has accounted for nearly 90% of the external costs of transportation (INFRAS, 2004). The transport sector represented worldwide more than a quarter of world energy consumption in 2004 (International Energy Agency, 2010). For that reason, we have to consider these *externalities* to ensure the sustainable growth of transportation in the world by reformulating logistics processes (Ubeda *et al.* (2011) and Faulin *et al.* (2011)).

This article is organized into four main sections. Following this introduction, section 2 describes and justifies the used methodology while section 3 presents the main results of the paper. Finally, the conclusion section describes the main ideas, policy implications, and potential avenues for future research.

\* Correspondence: Adrian Serrano-Hernandez, Department of Statistics and Operations Research, GILT Group, Institute of Smart Cities, Public University of Navarre, 31006 Pamplona, Spain  
E-mail: [adrian.serrano@unavarra.es](mailto:adrian.serrano@unavarra.es)



[NIJ2] Belloso, J. Juan. A., Faulin, J., and Serrano-Hernandez, A. (2015). Using multi-start biased randomization of heuristics to solve the vehicle routing problem with clustered backhauls. *Lecture Notes in Management Science*, 7: 15-20.

## Using multi-start biased randomization of heuristics to solve the vehicle routing problem with clustered backhauls

Javier Belloso<sup>1</sup>, Angel A. Juan<sup>2</sup>, Javier Faulin<sup>1</sup> and Adrián Serrano<sup>1</sup>

<sup>1</sup> Public University of Navarra, 31006 Pamplona, Spain  
(javier.belloso, javier.faulin, adrian.serrano)@unavarra.es

<sup>2</sup> Open University of Catalonia, 08018 Barcelona, Spain  
ajuana@uoc.edu

Proc. ICAOR 2015  
Vienna, Austria

### Abstract

**Keywords:**  
Biased randomization  
Clustered backhauls  
Heuristics  
Multi-start algorithms  
Vehicle routing problem

We consider the Vehicle Routing Problem with Backhauls (VRPB), where delivery and pick-up customers are to be served from a central depot. In particular, the group or cluster of delivery customers has to be served before the first pickup customer can be visited. Thus, the problem belongs to a sub-class called VRP with Clustered Backhauls (VRPCB). Our resolution procedure uses a multi-start approach designed to avoid the local minima and to be easily parallelizable. The algorithm employs a biased-randomized version of the classical savings heuristic, together with some local search processes. During the solution-construction process, the edges that connect one delivery customer with a pick-up customer are penalized to be chosen at a later stage. The savings list of edges is randomized using a skewed probability distribution. Some classical benchmark instances for the VRPB were selected in order to compare the efficiency of our approach.

### Introduction

The Capacitated Vehicle Routing Problem (CVRP) is a very well-known model to help making decisions in logistics and transportation issues (Toth and Vigo, 2014). The classical version of the CVRP aims at generating the minimum cost set of routes for a fleet of vehicles that have to satisfy the customers' requests. In this context, allowing not only deliveries but also pick-ups, then we are considering the General Pick-up and Delivery Problem (Savelsbergh and Sol, 1995). Thus, all goods delivered have to be loaded at the depot and all goods picked up have to be shipped to it. This class of problems is called Vehicle Routing Problem with Backhauls (VRPB). This paper focus on one of the VRPB variants: the VRP with Clustered Backhauls (VRPCB). Customers are either delivery or pick-up customers but cannot be both. Additionally, it is imposed that the cluster of delivery customers has to be served before the first pick-up customer can be visited. This cluster constraint is practically motivated by the fact that vehicles are often rear loaded. Hence, the on-board load rearrangement required by a mixed service is difficult –or even impossible– to carry out at customer locations. VRPB takes advantage of the unused capacity of a vehicle on the trip back to the depot and so, sender customers are considered as well. Our interest in the VRPB is motivated both by its great practical and theoretical importance. From the practical perspective, VRPB is frequently encountered by large companies who must transport goods from their production sites to other inter-company sites (linehauls). At the same time the production site must be supplied from vendors (backhauls) and/or other inter-company production sites located within the same geographic region (Goetschalckx and Jacobs-Blecha, 1989; Goetschalckx, 2011). A common example of backhaul loop can be found on linehaul customers that must return empty containers to their respective senders. Another example can be found in the grocery industry, where supermarkets and shops are the linehaul customers and grocery suppliers are the backhaul customers (Ubeda *et al.*, 2011). In the retail industry, large companies own many outlets to be supplied from the depot, and at the same time, the depots must be resupplied by the vendors located in the same region by visiting backhaul customers in distribution routes (Golden *et al.*, 1985). It has been widely recognized that in this mixed distribution-collection context, a significant saving in transportation costs can be achieved. Other applications can be considered: return of empty bottles, pallets, used batteries, etc.; delivery of new appliances accompanied by the pick-up of the old ones; recovery of defective or obsolete products, etc. The VRPB is also considered into the field of reverse logistics and Green Logistics (Demir *et al.*, 2014) that raise the necessity of bi-directional product flows. Significant cost reduction can be achieved by combining linehaul with backhaul customers as this results in less empty routes back to the depot and therefore in the reduction of gas emissions, as shown in Ubeda *et al.* (2011), and Parragh *et al.* (2008).

[NIJ3] Ubeda, S., Faulin, J., Serrano-Hernandez, A., and Arcelus, F. (2014). Solving the green capacitated vehicle routing problem using a Tabu search algorithm. *Lecture Notes in Management Science*, 6: 141-149.

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Lecture Notes in Management Science (2014) Vol. 6: 141-149  
6<sup>th</sup> International Conference on Applied Operational Research, Proceedings  
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ISSN 2008-0050 (Print), ISSN 1927-0097 (Online)

## Solving the green capacitated vehicle routing problem using a tabu search algorithm

Sergio Ubeda <sup>1</sup>, Javier Faulin <sup>1</sup>, Adrián Serrano <sup>1</sup> and Francisco J Arcelus <sup>2</sup>

<sup>1</sup> Department of Statistics and Operations Research, Public University of Navarre, Pamplona, Spain  
{sergio.ubeda, javier.faulin}@unavarra.es

<sup>2</sup> Department of Business Administration, University of New Brunswick, Fredericton, Canada  
arcelus@unb.ca

**Abstract.** This paper analyses how the tabu search can be successfully applied to solve the Green Capacitated Vehicle Routing Problems- GCVRP. This kind of problems has been described as the classical Capacitated VRP with a criterion of environmental emissions minimisation. This criterion is based on the calculation of carbon dioxide emissions from mobile sources, which is highly dependent on several factors such as speed, weather conditions, load and distance. A case study is given to show how green routes can be obtained and to analyze whether those routes also meet the efficiency objectives or not. The results show that a tabu search approach adapts the environmental criterion better than other procedures and also produces routes which are distance effective and environmental-friendly.

**Keywords:** environmental studies; CO2 emissions; distribution; vehicle routing; tabu search

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### Introduction

This paper discusses a variant of the standard version of the capacitated vehicle routing problem (CVRP) (Toth and Vigo, 2002), but with consideration of environmental issues, which is called the Green Capacitated Vehicle Routing Problem-GCVRP. Then, the estimations of fuel consumption and CO<sub>2</sub> emissions for mobile sources are needed, but these tasks usually require complex calculations. Thus, the only way to calculate emissions from VRP is by applying an average emission value per kilometre, but this procedure has been shown to be inaccurate (Van Woensel *et al.*, 2001) because it will lead to an important underestimation of the effective emissions. The problem studied in the present

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ICIL 2016

International Conference on Industrial Logistics  
September 28 – October 1, 2016, Zakopane, Poland**LOCATING A BIOREFINERY UNDER ENVIRONMENTAL  
CRITERIA: A GREEN FACILITY LOCATION PROBLEM****Adrian SERRANO-HERNANDEZ<sup>1</sup>, Javier FAULIN<sup>1</sup>, Mercedes SANCHEZ<sup>2</sup>,  
Javier BELLOSO<sup>3</sup>, Bartosz SAWIK<sup>4</sup>**<sup>1</sup>Department of Statistics and Operations Research, Institute of Smart Cities,  
Public University of Navarre, Pamplona,  
Spain<sup>2</sup>Department of Business Management, Public University of Navarre, Pamplona,  
Spain<sup>3</sup>Department of Mathematical Engineering and Computing,  
Public University of Navarre, Pamplona,  
Spain<sup>4</sup>Faculty of Management, Department of Applied Computer Science,  
AGH University of Science and Technology, Krakow,  
Poland**Abstract:**

*Underestimating facility location decisions may penalize its performance over time. Those penalties usually have been studied from the economic point of view analyzing its impact on profitability. At the same time, the concern about the obtaining of sustainability is gaining importance leading to seek for renewable energy sources to reduce greenhouse gas emissions. However, little attention has been paid on choosing a location considering environmental criteria. Thus, this work aims at determining a biorefinery location considering its impacts on natural resources. Thus, a mixed integer linear programming model is developed taking into account the crop location and the biomass production seasonality to obtain an apposite location that minimizes environmental impact.*

**Keywords:**

*Biorefinery, Logistics, Supply Chain Management, Facility Location Problem, MILP*

**1. INTRODUCTION**

Biorefineries evolve rapidly due to the fact of a quick answer to reduce the dependence of national economies from oil materials and their derivatives. This situation is trying to be solved by developing new energy alternatives from renewable resources. Within the group of renewable energies, the biomass, being the feedstock of a biorefinery, is an important option to replace the use of fossil fuels, especially in the transportation sector. This substitution can be done because biorefineries transform biomass into liquid fuel in internal combustion engines [1] and electricity for electric vehicles [2]. Most biorefineries have focused their interest and goals on bioethanol or biodiesel production contributing to such energy goal [3]. However, biofuels are produced in large quantities but are sold at low prices making its profitability strongly dependent on market conditions, which are very difficult to control (oil and biomass prices) what leads to high volatility business. The biorefinery concept has evolved into new scenarios where biofuel production is complemented with other high-value chemical commodities in order to remedy that situation. Once it has been collected, biomass is converted into energy (for instance electricity and

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## ASSESSING SERVICE QUALITY IMPROVEMENT THROUGH HORIZONTAL COOPERATION IN LAST-MILE DISTRIBUTION

Adrian Serrano-Hernandez<sup>(a)</sup>, Patrick Hirsch<sup>(b)</sup>, Javier Faulin<sup>(c)</sup>, Christian Fikar<sup>(d)</sup>

<sup>(a),(c)</sup> Public University of Navarra, Pamplona, Department of Statistics and Operations Research. Institute of Smart Cities. Campus Arrosadia, 31006 Pamplona, Spain

<sup>(b),(d)</sup> University of Natural Resources and Life Sciences, Vienna, Institute of Production and Logistics, Feistmantelstraße 4, 1180 Vienna, Austria

<sup>(a)</sup> [adrian.serrano@unavarra.es](mailto:adrian.serrano@unavarra.es), <sup>(b)</sup> [patrick.hirsch@boku.ac.at](mailto:patrick.hirsch@boku.ac.at), <sup>(c)</sup> [javier.faulin@unavarra.es](mailto:javier.faulin@unavarra.es), <sup>(d)</sup> [christian.fikar@boku.ac.at](mailto:christian.fikar@boku.ac.at)

### ABSTRACT

Horizontal cooperation is a relevant strategy that logistic service providers can follow in order to achieve greater efficiency. While literature has mainly focused on economic benefits, this article discusses the impact of horizontal cooperation on service quality in last-mile distribution. An agent-based simulation model is introduced to assess savings in lead times due to various horizontal cooperation agreements under consideration of trust related factors. Results of computational experiments show that cooperation enables companies to reduce lead times substantially, which increases service quality and competitiveness.

**Keywords:** Horizontal Cooperation, Coalition, Service Quality, Simulation, Last-mile Distribution

### 1. INTRODUCTION

Companies are facing significant challenges in their logistics activities. Growing competition due to globalization as well as increasing customer expectations on service quality require firms to be more efficient and competitive in the management of distribution operations. These issues are especially important for small and medium-sized enterprises (SME) that usually do not have the economic, human and technical resources needed to solve complex mathematical models related to logistics optimization. Additionally, in Europe, the logistics service providers (LSP) sector is often highly diverse, being mainly made of small companies, which are often family-owned (Crujssen et al. 2007). Thus, unlike large companies, SME can only take limit advantage of economies of scale and, therefore, require innovative concepts in order to stay competitive.

In order to facilitate competitiveness, SME can follow cooperation strategies with other companies. Interfirm agreements imply, on the one hand, maintaining an independent legal personality and, on the other hand, the establishment of processes, protocols, or frameworks that enable the cooperation in business-related projects such as logistics activities. When

cooperation takes place between companies that belong to the same echelon of the supply chain, it is commonly denoted as horizontal cooperation (e.g., Lambert et al. 1996, European Union 2001, Crujssen et al. 2007). Therefore, horizontal cooperation is a particular typology of interfirm collaboration, in contrast to vertical collaboration where agreements take place among different stages of the supply chain, i.e., between suppliers, manufacturers and retailers. Supply Chain Management (SCM) aims to efficiently integrate the actors that are active within a particular supply chain in order to provide products in the right quantity as well as at the right time and location in such a way that total costs of all actors are minimized and service level is satisfied (Chopra and Meindl 2016). While numerous work on SCM is found in the literature, horizontal cooperation is still in its early stages (Leitner et al. 2011).

Concerning horizontal cooperation, last-mile distribution, the link between the supply chain and the final destination, is of particular interest as it is responsible for up to 28% of total logistics costs (Roca-Riu et al. 2012). This delivery often takes place in urban environments, in which case it is commonly denoted as urban freight distribution. Even though urban distribution has a key role in the economic development of cities, it has many challenges to cope with (Taniguchi et al. 2016) as urban areas are growing rapidly. According to the United Nations (2014), 54 % of the world's population was living in urban areas in 2014 and 66 % are expected to do so by 2050. Additionally, the rapid development of information and communication technologies have led to new sales channels such as e-commerce (Deloto and Chen-Burger 2015), further increasing urban freight distribution. Thus, efficiency in urban distribution, i.e. enabling higher frequency in deliveries and shorter times, is a key factor for the competitiveness of urban LSPs.

To support last-mile distribution and to investigate the impact of horizontal cooperation, this article evaluates benefits derived from the implementation of various horizontal cooperation agreements from a customer point of view. Therefore, the objective is to reduce lead

